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Javier Cravino, Andrei A. Levchenko and Marco Rojas

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Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
www.cepr.org

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JEL Classification: E2, O1, O4

Keywords: aging, structural transformation, deindustrialization

Javier Cravino - jcravino@umich.edu
University of Michigan and NBER

Andrei A. Levchenko - alev@umich.edu
University of Michigan and CEPR

Marco Rojas - rojasmi@umich.edu
University of Michigan

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Javier Cravino
University of Michigan
and NBER

Andrei A. Levchenko
University of Michigan
NBER and CEPR

Marco Rojas
University of Michigan

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1 Introduction

Economic growth is accompanied by large reallocations of economic activity across broad sectors, a phenomenon known as structural transformation (Kuznets, 1957). In advanced economies, the structural transformation process is associated with a decline in the relative size of the Agriculture and Manufacturing sectors and a corresponding rise in the Service sector. Traditional theories that attempt to rationalize this process have relied on non-homothetic preferences with a high income elasticity for services (e.g. Kongsamut et al., 2001), or on a technology-driven increase in the relative price of services coupled with a low elasticity of substitution across sectors (Baumol, 1967; Ngai and Pissarides, 2007).

This paper documents and quantifies the role of population aging in the structural transformation process. Older individuals devote a larger share of their expenditures to services, thus the relative size of the service sector grows as the population ages. We show that, across a large sample of countries, increases in population age are accompanied by a rise in the relative size of the service sector. Using household-level data for the US, we document large differences in sectoral expenditure shares across households of different ages, with older households spending relatively more on services. We then use a shift-share decomposition and a quantitative model of structural change to quantify how much of the rise in the relative size of the service sector in the US over the period 1982-2016 can be accounted for by changes in population age.

To document how structural transformation is related to population aging across countries and time, we use multiple data sources following the Handbook chapter by Herrendorf et al. (2014). Across many countries and years, and several datasets, the service shares of employment, value added, and consumption expenditures are positively related to population aging. Importantly, this empirical regularity persists when controlling for the (possibly nonlinear) relationship between the service shares and income per capita that has been emphasized in the previous literature. After controlling for income, a 1 percentage point increase in the fraction of population that is over 65 is associated with a 1.3-1.5 p.p. increase in the service shares of value-added and employment, and a 0.7 p.p. increase in the service share of consumption expenditures.

We then use household-level data from the US Consumer Expenditure Survey (CES) to document large differences in sectoral expenditure shares across households of different ages. Our data cover the 1982-2016 period and have been widely used to study how service expenditures vary with household income. Older households spend significantly more on services, a pattern monotonic in household age throughout the age distribution. Compared to households in their early 30s, the service expenditure shares of households in their early 60s (resp. over 80) are 8 (resp. 27) percentage points higher. These differences are stable over the sample period, and are equally large when controlling flexibly for household income. The largest differences in expenditure patterns arise in Health, Utilities, and Domestic Services, which are intensively consumed by the old, and in Vehicle Purchases, Leasing, and Gasoline and Motor Oil, which are intensively consumed by the young.[1]

We quantify the contribution of population aging to structural change in the US in two complementary ways. First, we perform a simple within-between decomposition of the change in the service expenditure share between 1982 and 2016 (the sample period available in the CES). We write the change in the aggregate service expenditure share as a sum of two terms, one capturing changes in the service share of expenditures within each household-age group, and another capturing changes in the relative aggregate expenditure of the age groups. This decomposition shows that changes in the age-structure of the population accounted for 20% of the observed change in the service expenditure share over this period.

We then use our data along with a structural model to evaluate the relative contributions of changes in relative prices, real income, and the age distribution to the structural change process. We use a two-sector model with heterogenous households whose preferences over goods and services take the Price-Independent Generalized Linear (PIGL) form, augmented with age-specific taste shifters. These preferences were introduced by Muellbauer (1975, 1976), and recently applied to the analysis of structural change by Boppart (2014). In the model, the household-specific expenditure share on goods depends on the relative price of goods vs. services, the household real expenditures, and the household taste shifter. An advantage of the PIGL preferences is that household-level expenditures can be easily aggregated, so that the aggregate expenditure shares are a function of relative prices, aggregate income per capita, and a weighted average of the taste shifters, with weights that correspond to the relative importance of each age group in total expenditures.

The relative strengths of the mechanisms that determine structural change in the model depend on the elasticity of substitution across sectors, the income elasticity of each sector, and the relative size of the age-specific taste shifters. Following Boppart (2014), we use

[1] It is well-known that the CES only contains health expenditures paid directly by households (i.e., it excludes payments made by Medicare, Medicaid, or private insurance). According to the National Health Expenditure Survey (NHES), out-of-pocket health expenses represent a similar fraction of total health expenses across the age distribution, so the differences in health expenditures persist after adding non-out-of-pocket expenditures. Online Appendix B.3 repeats our analysis after rescaling household-specific expenditure shares in the CES to match the aggregate expenditures reported in National Accounts data.

the model's structural equations for the household-specific expenditure shares and cross-sectional household data to estimate the sectoral income elasticities, and use the same methodology to estimate age-specific taste shifters. We then use the structural equation for the aggregate expenditure shares and aggregate data on expenditures and prices to estimate the parameter governing the elasticity of substitution between goods and services.

Having estimated the preference parameters allows us to decompose the log change in the services share additively into the components driven by aging, technology, real income growth, and a residual which can be interpreted as arising from age- and income-neutral changes in preferences over time. We find that population aging played a significant role in the increase in the expenditure share of services during this period, accounting for about 20 percent of the total. The increase in the relative price of services accounted for about 40% of the overall change, the rise in the real incomes another 20%, and residual taste changes the remaining 20%. Finally, we combine our estimates of age-specific taste shifters for services with population estimates to project that the US service expenditure share will increase by a further 0.1 log points between today and 2050. The impact of aging on structural transformation is set to become stronger in the future compared to its past role.

Our paper contributes to a large literature that attempts to rationalize the structural transformation process (see the recent survey by Herrendorf et al., 2014). Most theories focus on the non-homotheticity of the relative demand for services with respect to income (e.g. Kongsamut et al., 2001), or on changes in relative prices driven by differential long-growth rates of productivity (e.g. Ngai and Pissarides, 2007) or capital deepening and factor intensity differences across sectors (Acemoglu and Guerrieri, 2008). Alternative recent theories for the structural transformation process have also emphasized the roles of international trade (Matsuyama, 2009; Uy et al., 2013; Cravino and Sotelo, 2019), home production (Buera and Kaboski, 2012), and changes in the labor supply driven by changes in schooling (Porzio et al., 2020), or by cohort-specific occupational choices (Cociuba and MacGee, 2018; Hobijn et al., 2018). We contribute to this literature by quantifying a complementary demand-side mechanism for the structural transformation process. Closest to our cross-country empirical results is Siliverstovs et al. (2011), who relate employment shares in 9 goods and service sectors to aging in a panel of countries. Brembilla (2018) argues that aging slows down the process of structural transformation because the price elasticity of demand for services is lower for the old compared to the young. In contrast, our analysis indicates that aging speeds up the structural transformation process since older households consume more services.

Our analysis is also related to the quantitative literature that combines the mechanisms listed above to evaluate their relative importance. Herrendorf et al. (2013) show that the relative strength of the income and substitution forces depend on whether expenditures and prices are measured using expenditure or value-added data. Boppart (2014) and Comin et al. (2021) introduce the PIGL and Generalized CES preferences, respectively, and re-evaluate these mechanisms allowing for non-vanishing long-run income effects. Swiecki (2017) uses a framework that allows for international trade across countries and shows that substitution effects are most important in developed countries, while income effects are more important in accounting for the shift out of agriculture during the early stages of the development process. We contribute to this body of work by showing that expenditure patterns differ across the age distribution, and thus an important portion of the structural change process may be driven by the population composition changes.

Finally, our paper builds on the literature documenting the differences in consumption patterns across the age distribution. Hobijn and Lagakos (2005) show that differences in spending patterns by age lead to differences in CPI inflation across age groups. Like us, they find that the largest disparities are in health care expenditures (disproportionally consumed by the elderly) and gasoline prices (disproportionally consumed by the young). Aguiar and Hurst (2013) analyze consumption expenditures on non-durable goods, and find large differences in consumption patterns of young vs. old households in food, nondurable transportation, and clothing and personal care. Hall and Jones (2007) and Reinhardt (2003) explore, theoretically and empirically, the role of aging in health expenditures. We contribute to this literature by quantifying how age-related differences in consumption patterns affect the structural transformation process.

The rest of the paper is organized as follows. Section 2 describes the relationship between population age and the share of services in the economy across countries, US households, and time. Section 3 quantifies the contribution of the observed population aging to structural change, and Section 4 concludes. The Online Appendix collects additional exercises and robustness results.

2 Population aging and structural transformation: Facts

This section presents empirical evidence documenting that population aging is systematically related to a shift in economic activity from Agriculture and Manufacturing sectors towards Service sectors. We organize our evidence in two sections, one showing how structural transformation relates to population aging across countries and time using aggregate data, and another showing how sectoral expenditure shares vary with household age using microdata for the US.

2.1 Cross-country evidence

We start by describing how population aging is related to structural transformation across space and time. The empirical analysis follows the approach in the Handbook chapter by Herrendorf et al. (2014), who document how economic activity reallocates across Agriculture, Manufacturing, and Services as income per capita rises. We use the same data sources and empirical strategy to document how this reallocation is related to population aging. We document the relation between population aging and the share of services in (i) employment; (ii) value added, and (iii) consumption, after controlling for changes in income.

With this in mind, we take sectoral value added and employment shares for a broad set of developed countries from EU KLEMS, which is compiled by the Groningen Growth and Development Center. The database reports hours worked and value added by sector for a sample of 20 developed countries over the 1970-2007 period. Consumption shares come from the OECD Statistics. Consumption shares can differ from value added and employment shares since they do not include investment nor exports, and they do include imports. OECD statistics report consumption for 11 countries in 16 expenditure categories for the 1970-2007 period. We follow Herrendorf et al. (2014) and classify Food Consumption as Agriculture, Semi-, Durable-, and Non-Durable Goods minus Food Consumption as Manufacturing, and the remaining categories as Services. The aging indicator is the share of the population that is 65 or older, taken from the World Development Indicators.

We evaluate the relation between population aging and the structural transformation process by estimating the following regressions:

$$\omega_{i,t}^{j} \quad = \quad \alpha_i^j + \beta^j Age_{i,t} + \gamma_1^j gdp\_pc_{i,t} + \gamma_2^j gdp\_pc_{i,t}^2 + \varepsilon_{i,t}^j. \tag{1}$$

Here, $\omega_{i,t}^{j}$ is the share of employment, value-added, or consumption in sector j in country i in year t, α_i^j is a country fixed effect, $gdp\_pc_{i,t}$ is the log of GDP per capita in country i year t, and $Age_{i,t}$ is population age in country i in year t, measured either by the share of population that is over 65 or by the average age in the country. We cluster standard errors by country.

Table 1: Population aging and the sectoral shares of employment and value added

	(1)	(2)	(3)	(4)	(5)	(6)
	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$
Employment Share						
Share of pop 65+	-1.980***	-0.653**	-1.351***	-0.877**	3.330***	1.530***
	(0.440)	(0.285)	(0.323)	(0.381)	(0.586)	(0.490)
Log GDP per capita		-1.240***		1.243***		-0.00306
		(0.0802)		(0.234)		(0.229)
(Log GDP per capita)^2		0.0590***		-0.0677***		0.00874
		(0.00456)		(0.0133)		(0.0126)
R^2	0.802	0.951	0.487	0.681	0.825	0.924
Value Added Share						
Share of pop 65+	-1.012***	-0.0575	-1.533***	-1.252***	2.545***	1.309***
	(0.261)	(0.105)	(0.297)	(0.381)	(0.353)	(0.352)
Log GDP per capita		-0.705***		1.528***		-0.823***
		(0.0402)		(0.166)		(0.138)
(Log GDP per capita)^2		0.0326***		-0.0818***		0.0492***
		(0.00234)		(0.00990)		(0.00812)
Observations	707	707	707	707	707	707
R^2	0.700	0.953	0.579	0.760	0.772	0.874

Notes: This table reports the results of estimating equation (1). The outcome variables are employment shares (top panel) and value added shares (bottom panel) in agriculture (*Agr*), manufacturing (*Man*) and services (*Ser*). Population age is proxied by the share of population over 65. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table 2: Population aging and the sectoral consumption share, OECD

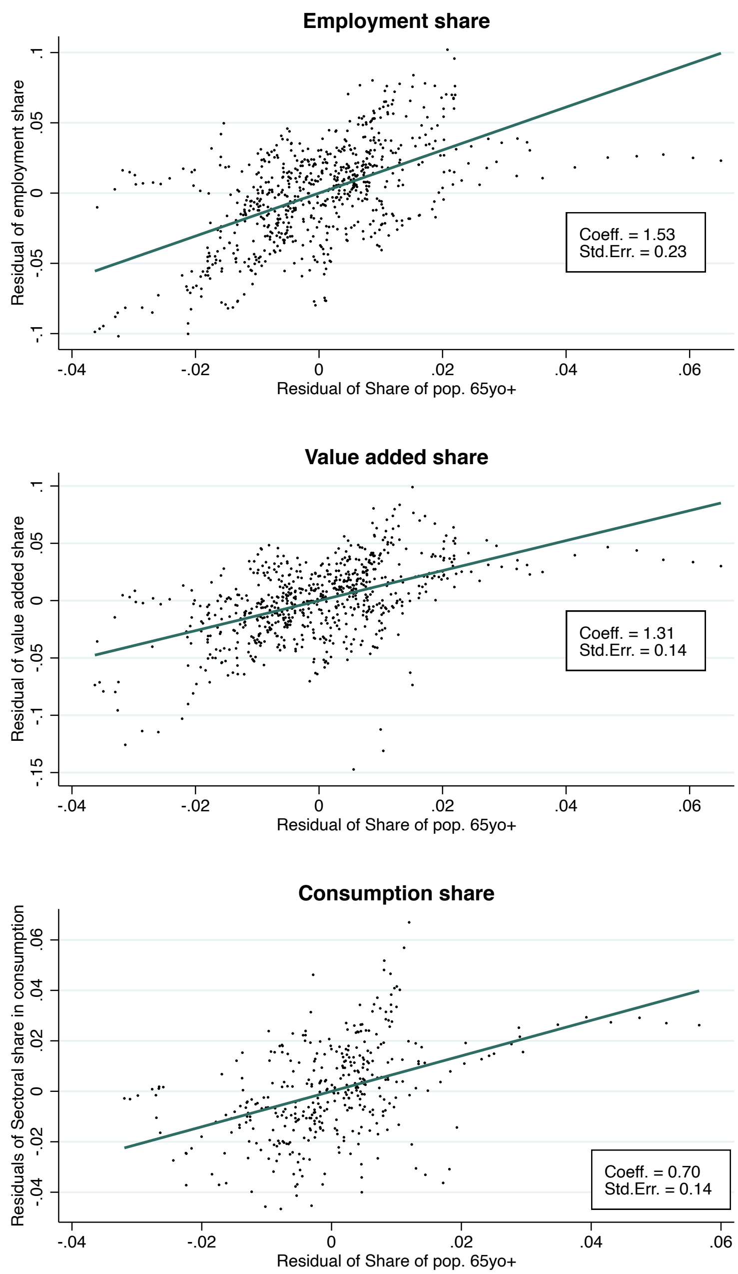
	(1) $\omega_{i,t}^{Agr}$	(2) $\omega_{i,t}^{Agr}$	(3) $\omega_{i,t}^{Man}$	(4) $\omega_{i,t}^{Man}$	(5) $\omega_{i,t}^{Ser}$	(6) $\omega_{i,t}^{Ser}$
Share of pop 65+	-1.702**	-0.498*	-0.793**	-0.205	2.496***	0.703***
	(0.560)	(0.261)	(0.293)	(0.271)	(0.614)	(0.219)
Log GDP pc		-0.455***		0.714***		-0.259
		(0.136)		(0.170)		(0.145)
(Log GDP pc)^2		0.0181**		-0.0406***		0.0225**
		(0.00780)		(0.00987)		(0.00852)
Observations	377	377	377	377	377	377
R^2	0.767	0.957	0.803	0.860	0.789	0.948

Notes: This table reports the results of estimating equation (1). The outcome variables are consumption expenditure shares (bottom panel) in agriculture (*Agr*), manufacturing (*Man*) and services (*Ser*). Population age is proxied by the share of population over 65. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table 1 reports the results of separately estimating equation (1) for each sector. Both the shares of hours worked and of value added are decreasing in income per capita in the Agriculture and Manufacturing sectors, but increasing in the Service sector, in line with the evidence surveyed by Herrendorf et al. (2014). The coefficient of interest β^j is negative for Agriculture and Manufacturing, and positive for Services, indicating that indeed aging is associated with a reallocation of economic activity towards services, even after controlling for changes in income. These findings are robust to measuring shares both in terms of value-added or employment, and to using either of our two measures of population age. Table 2 reports the analogous results for consumption. The coefficients are economically significant. The 0.7 coefficient in column 6 of Table 2 implies that, other things constant, if the US had the age structure of Japan in 2007, its share of services in consumption would be 5 percentage points higher.

Figure 1 plots employment, value added, and consumption shares, residualized with respect to the log of GDP per capita, the log of GDP per capita squared, and country fixed effects against population age. For all three outcome variables, there is a pronounced positive relationship between population aging and the share of services.

Figure 1: Residualized service sector shares



Notes: Each dot represents a country-year. On the y-axis is the residual of a regression of the share of services in hours worked (top panel), value added (middle panel), or consumption (bottom panel) on log GDP per capita, log GDP per capita squared, and country fixed effects. On the x-axis is the residual of a regression of the share of the population that is 65+ on GDP per capita, GDP per capita squared, and country fixed effects. The boxes report the slope coefficient and the standard errors clustered at the country level.

The Online Appendix presents a comprehensive analysis of the cross-country data. In particular, it: (i) shows unconditional relationships; (ii) uses average age as an alternative aging variable; (iii) adds further controls, such as trade openness, government size, and relative price trends, and (iv) uses sectoral shares data from other datasets (WDI and the UN), that cover a much broader range of countries.

Cross-country data let us establish macro-level correlations between aging and sectoral expenditure shares across time and space. The downside of the macro approach is that it is difficult to distinguish between the effects of aging *per se* and other confounding factors, such as other country characteristics or long-run trends. The following Section overcomes these limitations by using instead household-level microdata for the US.

2.2 Household-level evidence

Our household-level data come from the US Consumer Expenditure Survey (CES) and cover the 1982-2016 period. We use the Interview Module of the CES, which surveys about 12,000 households per year. The Interview Module collects households' responses about their purchases across 350 distinct expenditure categories, as well as other demographic information at the household level. We consider urban households of all ages and drop household/quarter observations if either service expenditures, goods expenditures, or pre-tax income are zero.

We weight the households using household weights in the *FMLI.dta* files of the CES. The CES interviews households up to four times about their expenditures in the preceding quarter to capture annual expenditures. Since our analysis is at the calendar quarter level, we follow Cravino et al. (2020) and multiply the raw CES weights by the fraction of months from each interview corresponding to each given calendar quarter. The sum of our modified weights in each calendar quarter approximately adds up to the number of US urban households. We use the average age of household members as the measure of age for our baseline analysis. Online Appendix B.1 shows that our results are robust to using the reference person's age, i.e. age of the household head.

We aggregate expenditures into goods and services following Aguiar and Bils (2015).[2]

[2]See Appendix Table A4 for the breakdown. Relative to Aguiar and Bils (2015), we disaggregate two sectors considered goods in that paper – "Personal Care" and "Other vehicle expenses" – into their service and goods sub-components. For instance, instead of counting all "Personal Care" expenditures as goods, we take advantage of the fact that the CES disaggregates this category into "Personal Care Goods" and "Personal Care Services," and apportion those to goods and services accordingly. None of the quantitative or qualitative conclusions change if we use the exact Aguiar and Bils (2015) classification without this refinement (results available upon request). We classify 87 percent of the non-housing expenditures in the CES as either goods or services (following Aguiar and Bils, 2015, we do not classify "Pensions" and "Personal Insurance").

For our baseline results, we focus on how the share of non-housing service expenditures to the overall non-housing expenditures changes with household age. We do not include housing in expenditure because in the CES the rental value of owner-occupied housing is self-reported and thus may not be directly comparable to rent payments for renters. Since home ownership rates change substantially over the life cycle, the switches between owner-occupied implicit rent value and actual paid rent may complicate the comparison across age groups. Online Appendix B.1 reports results including housing in the analysis and shows that the treatment of housing does not alter the main conclusions.

The top panel of Figure 2 plots the expenditure share on services across households of different ages. Each color of the dots represents a different period. There is a clear positive monotonic relationship between the service expenditure share and the average age of the household members. The differences are large: service expenditure shares of households in their 60s are about 25 percent larger than for the households in their 30s (0.5 vs. 0.4). Households in their 80s have expenditure shares in services that are almost 70% higher than those in their 30s (0.68 vs 0.40). These patterns are stable over time. While later periods tend to feature higher service expenditure shares overall, the cross-age differences are pronounced in all time periods.

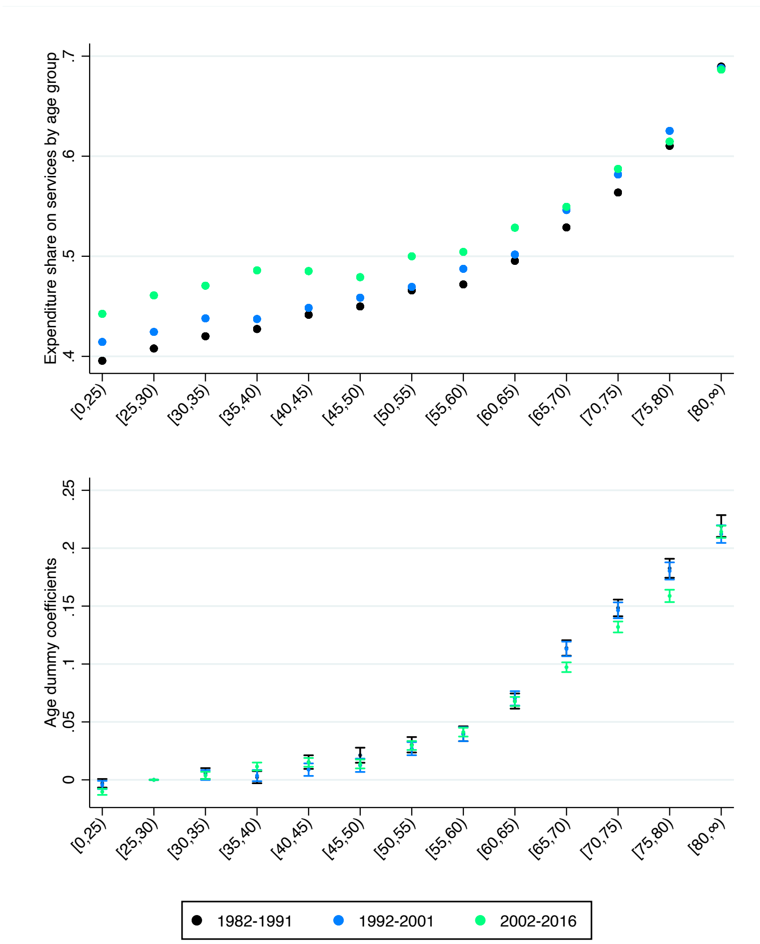
Controlling for income The unconditional patterns in Figure 2 may arise from income differences across age groups. This section shows that this is not the case. To control flexibly for income, we estimate a regression that projects the service expenditure shares on age dummies, while controlling for income decile dummies and other household characteristics and region-time fixed effects:

$$\omega_t^{s,h} \quad = \quad \delta^a + \delta^{inc} + \gamma X_{r,t}^h + \delta_{r,t} + \varepsilon_t^{s,h}. \tag{2}$$

Here $\omega_t^{s,h}$ is the service expenditure share of household h at time t, δ^a are household age group dummies and δ^{inc} are income decile dummies (the income decile dummies are provided by the CES). X_{rt}^h are demographics dummies for the number of household members (2, 3-4, 5+) and dummies for the number of household earners (1, 2+). These are typically used in the literature (e.g. Aguiar and Bils, 2015). Following Comin et al. (2021) we also control for differences in household-specific prices by including region-time dummies, $\delta_{r,t}$. The implicit assumption behind this control is that households within a region face the same prices.

We estimate equation (2) separately for each decade for which the CES data are available. The bottom panel of Figure 2 plots the age group dummies, which measure differences in service expenditure shares of the age group relative to age group 25-30. The 95% confidence bands based on standard errors clustered by household are depicted around the point estimates. There are large differences in service expenditures across households of different ages, even conditioning on income and prices. These conditional differences are nearly as large as the unconditional ones reported in Figure 2. As in the raw data, households in their 60s have service expenditure shares 10-12 percentage points higher than households in their 30s, and households in their 80s' service expenditure shares are more than 20 points higher. The age dummies are precisely estimated, and quite stable over time.

Figure 2: Service consumption by average age of household members



Notes: The top panel displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Online Appendix B.1 presents additional descriptive statistics regarding service consumption patterns in the CES. Appendix Figure A12 reproduces Figure 2 using the age of the reference person (i.e. household head) instead of average age in the household, and shows that the results are virtually unchanged. Additionally, Appendix Figure A13 replicates Figure 2 adding housing as part of the overall consumption and services. Appendix Figure A14 adds age-group-specific price indices as controls in equation (2).

Decomposing consumption differences Table 3 shows the differences in expenditure shares across young and old households for the main consumption categories. It reports the difference in expenditure shares for each category for the 25-30 vs. the age groups starting at 60-65. Unsurprisingly, the largest disparity arises in health expenditures, where the consumption expenditure share of the 60-65 (80+) age group is 5.6 (15.3) percentage points larger than that of the 25-30 age group. The table shows that the elderly also spend relatively more on Cash Contributions, Domestic Services, and Utilities. In contrast, for Vehicle Purchasing and Leasing, the expenditure share of the 60-65 (80+) age group is 3.8 (11.24) percentage points smaller than that of the 25-30 age group.

It is worth noting that the differences in consumption patterns across age groups are not mainly driven by retirement. The CES contains an indicator for whether the reference person in the household is retired. We can include this indicator when estimating equation (2). When controlling for age dummies, the retirement dummy has at most a modest positive effect on the service expenditure share. In contrast, the age dummies are mainly unchanged after including retirement as a control (results available upon request).

Table 3: Expenditure shares by consumption category relative to age group 25-30

	Age groups				
	60-65	65-70	70-75	75-80	80+
Health	5.62	7.90	10.17	12.42	15.25
Cash contributions	3.41	4.44	5.59	6.45	9.48
Domestic services (excl. childcare)	1.45	1.77	2.15	2.85	6.05
Utilities	1.06	1.23	1.88	2.57	3.41
Personal care services	0.13	0.20	0.30	0.36	0.44
Food at home	-0.89	-0.57	0.03	0.51	0.45
Personal care goods	-0.01	-0.01	-0.01	-0.02	-0.01
Public transport	0.37	0.36	0.25	0.18	-0.41
Tobacco	0.03	-0.17	-0.38	-0.58	-0.77
Childcare	-0.85	-0.85	-0.86	-0.87	-0.80
Shoes and other apparel	-0.37	-0.47	-0.58	-0.79	-0.85
Children's clothing	-0.76	-0.77	-0.88	-0.94	-1.03
Entertainment fees, adm., reading	-0.08	-0.14	-0.32	-0.61	-1.04
Alcoholic beverages	-0.33	-0.46	-0.64	-0.84	-1.04
Furnitures and Fixtures	-0.17	-0.30	-0.62	-0.83	-1.21
Appliances	0.14	-0.20	-0.49	-0.74	-1.36
Men's and women's clothing	-0.32	-0.57	-0.73	-1.13	-1.69
Car maintenance, repairs, insurance	-0.31	-0.55	-0.71	-0.78	-1.84
Food away from home	-0.55	-0.77	-1.17	-1.64	-2.26
Entertainment equipment	-0.20	-0.83	-1.78	-2.23	-2.80
Education	-2.63	-2.86	-2.90	-2.80	-2.99
Gas	-0.98	-1.41	-1.89	-2.48	-3.70
Vehicle purchasing, leasing	-3.75	-4.98	-6.41	-8.04	-11.24
Services	7.61	10.73	14.37	18.12	25.26

Notes: This table reports the differences in expenditure shares across the major consumption categories between age groups starting at 60-65 and households aged 25-30 in the CES.

Accounting for differences between CES and National Accounts data It is well known that the aggregated expenditure shares in the CES do not match those in the Personal Consumption Expenditure module of the National Income and Product Accounts compiled by the BEA. One reason for this discrepancy is that the CES only reports out-of-pocket expenses by private households, which may differ from economy-wide aggregate consumption and misrepresent expenditure differences across households. This may be especially salient in healthcare, since the CES data do not include spending by Medicaid, Medicare, and private insurance for services rendered to the household. Appendix Table A6 reports the shares of out-of-pocket expenditures in total health expenditures in National Health

Expenditure Survey (NHES) in the first and last year available in that survey, by broad age groups. Out-of-pocket expenditures represent a similar fraction of the total health expenditures across the age distribution. Thus, the relative health expenditure differences across the age distribution would persist after adding the non-out-of-pocket expenses.

With this in mind, we map our analysis to the National Accounts data, by augmenting the CES data with data from the Personal Consumption Expenditures (PCE) from the BEA. In particular, we rescale the expenditures in each consumption category to match aggregate consumption expenditures by category in the National Accounts (PCE BEA) data. These rescaled data reproduce the aggregate sectoral expenditure shares in the BEA, while preserving the heterogeneity across households present in the CES. Online Appendix B.3 details this procedure and replicates the results in this section and Section 3 using the rescaled dataset, and shows that the results are similar to the baseline.[3]

3 Accounting for structural change in the US

This section quantifies the contribution of observed changes in the age distribution to the observed changes in sectoral consumption shares in the US between 1982 and 2016. We conduct this exercise using two alternative methodologies. The first is a shift-share decomposition of the increase in the share of services in total consumption into the part that arises from reallocation of expenditures between age groups vs. changes in expenditures within age groups. The second is a quantitative model of structural transformation that allows us to compare the contribution of population aging to the contributions of the income and price effects that have been the focus of most of the structural transformation literature.

3.1 Within-between decomposition

We start with a decomposition of the observed rise in the share of services in total consumption in the CES between 1982 and 2016. We can write the share of services in aggregate consumption as:

$$\Omega_t^s = \frac{\sum_a e_t^{s,a}}{\sum_a \sum_j e_t^{j,a}} = \sum_a \omega_t^{s,a} \times s_t^a, \tag{3}$$

[3]Rescaling the CES data using NHES is challenging because the expenditure categories in the CES do not map readily into those in NHES, as the former presents the expenses from the perspective of the household, whereas the latter records the sources of revenue of the healthcare provider. In addition, NHES by age group only goes back to 2002.

where $e_t^{j,a}$ are total consumption expenditures by age group a in consumption sector j, $\omega_t^{s,a} \equiv \frac{e_t^{s,a}}{\sum_j e_t^{j,a}}$ is the share of services in total expenditures by age group a, and $s_t^a \equiv \frac{\sum_j e_t^{j,a}}{\sum_a \sum_j e_t^{j,a}}$ is the share of age group a in aggregate expenditures. Letting $\Delta x \equiv x_1 - x_0$ and $\overline{x} \equiv [x_1 + x_0]/2$ denote the change and the average of a variable across periods $t = 1$ and $t = 0$ we can write:

$$\Delta\Omega^s = \underbrace{\sum_a \Delta\omega^{s,a} \cdot \overline{s}^a}_{\text{Within}} + \underbrace{\sum_a \overline{\omega}^{s,a} \cdot \Delta s^a}_{\text{Between}}. \tag{4}$$

Equation (4) expresses the change in the service share of expenditures as the sum of two terms. The term labeled 'Within' captures changes in the age-specific expenditure shares, $\Delta\omega^{s,a}$, while the term labeled 'Between' captures changes in the share of age group a in aggregate expenditures, Δs^a.

We take equation (4) to the data by breaking the US population into the 13 age groups as in Section 2.2, measuring age both by the average age of all household members and by the age of the household head. Panel A of Table 4 reports the terms $\omega_t^{s,a}$ and s_t^a in equation (3) for each age group in 1982 vs. 2016. As already documented in Figure 2, older households allocate a significantly larger fraction of their expenditures towards services than younger ones: both in 1982 and 2016, the share of expenditure in services is more than 50% higher for households over 80 than for those aged 25-30. In addition, the table shows a large increase in the share of expenditures that is accounted for by older households: households 65 and older accounted for 10.4 percent of total expenditures in 1982, and 17.1 percent in 2016, a 64% increase. The share of expenditures that goes to households 80 and older nearly tripled, going from 1.2 to 3.4 percent. The counterpart of this increase is the decline in the share of expenditures that goes to households 30 and younger, from 47.3 to 31.6 percent.

Panel B of Table 4 reports the results of the decomposition in equation (4). The share of services in total expenditures increased by 8.5 percentage points during the 1982-2016 period. The table shows that 1.85 percentage points, about a fifth of the increase, are attributed to between age group changes in expenditures. The remainder is attributed to changes in expenditure shares within groups. The table shows that the numbers are similar if we instead measure household age by the age of the household head. Appendix Table A5 shows that the results are somewhat smaller though still economically significant if we count housing as part of service expenditures. The decomposition in (4) is implemented using age-specific total expenditure shares s^a, which change both due to

Table 4: Population aging and changes in the services share

Panel A: Expenditure shares across the age distribution

	Pop $_{1982}$	s^a_{1982}	$\omega^{s,a}_{1982}$	Pop $_{2016}$	s^a_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	31.2	38.8	20.4	19.8	47.2
25-30	13.5	16.1	39.9	11.4	11.8	47.6
30-35	9.4	11.2	42.1	9.4	10.8	50.3
35-40	6.2	7.6	43.0	7.1	7.9	49.5
40-45	4.6	5.4	45.4	5.9	6.5	53.4
45-50	3.6	4.0	45.6	5.2	5.5	51.4
50-55	3.8	4.0	45.7	6.1	6.1	51.4
55-60	5.1	4.9	47.4	6.7	6.9	51.9
60-65	5.7	5.2	50.6	7.5	7.8	58.1
65-70	5.9	4.5	53.0	6.8	6.3	56.7
70-75	4.3	2.9	58.7	5.1	4.6	57.4
75-80	3.3	1.8	59.5	3.4	2.8	60.8
80+	2.9	1.2	67.5	5.0	3.4	69.6

Panel B: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.0663	78.2	0.0675	79.7
Between	0.0185	21.8	0.0172	20.3
Total	0.0848	100	0.0848	100

Notes: In Panel A, 'Pop' reports the share of the population in each age group, and s^a_t and ω^a_t are defined as in Equation (4). Panel B reports the results of the decomposition in equation (4). 'Average' uses the average age across all household member as the age of the household. 'Reference' uses the age of the head in the household.

demographics and the age distribution of income. Appendix B.4 shows that most of the Between effect documented in this section is due to demographics rather than the changing age distribution of income.

3.2 Structural model

This section sets up a model to quantify the contribution of changes in population age, income, and relative prices to the structural transformation process in the US. We study an economy populated by N_t households indexed by h that are heterogeneous in their preferences and their expenditure levels e^h_t. Households consume goods (g) and services

(s). The indirect utility of household h takes the form:

$$\mathcal{V}^h\left(P_t^s, P_t^g, e_t^h\right) = \frac{1}{\epsilon}\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon} - \frac{\nu_t^h}{\gamma}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma} - \frac{1}{\epsilon} + \frac{\nu_t^h}{\gamma}, \tag{5}$$

where P_t^s and P_t^g are the prices of goods and services, and the parameters satisfy $0 \leq \epsilon \leq \gamma \leq 1$ and $\nu_t^h \geq 0$. This utility function belongs to a subclass of Price Independent Generalized Linearity (PIGL) preferences (Muellbauer, 1975, 1976; Boppart, 2014), with household-specific taste shifters ν_t^h. Using Roy's identity, we can show that expenditure shares are given by:

$$\omega_t^{g,h} \equiv \frac{e_t^{g,h}}{e_t^h} = \nu_t^h \left[\frac{P_t^s}{e_t^h}\right]^{\epsilon}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}, \tag{6}$$

where $e_t^{j,h}$ is the expenditure by h on sector j, and $\omega_t^{s,h} \equiv \frac{e_t^{s,h}}{e_t^h} = 1 - \omega_t^{g,h}$. The aggregate expenditure share on goods is:

$$\Omega_t^g \equiv \frac{\sum_h e_t^{g,h}}{\sum_h e_t^h} = \left[\frac{P_t^s}{e_t}\right]^{\epsilon}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\frac{1}{N_t}\sum_h \nu_t^h\left[\frac{e_t^h}{e_t}\right]^{1-\epsilon},$$

where $e_t \equiv \frac{1}{N_t}\sum_h e_t^h$ denotes average expenditures per household. Aggregate shares depend on real per capita expenditures in units of services, $\frac{e_t}{P_t^s}$, the relative price of goods vs. services, $\frac{P_t^g}{P_t^s}$, the extent of income inequality, $\frac{e_t^h}{e_t}$, and the taste shifters, ν_t^h.

In what follows we assume that households can be grouped according to their age, and denote the number of households of age a by N_t^a, with $\sum_a N_t^a = N_t$. We further assume that the taste shifters take the form $\nu_t^h = \nu_t \mu^a \mu_t^h$, with $\frac{1}{N_t}\sum_h \mu_t^h = 1$. This implies that the household-specific taste shifter has an aggregate component ν_t, an age-specific component μ^a, and an idiosyncratic component μ_t^h. The aggregate expenditure share can then be written as:

$$\Omega_t^g = \left[\frac{P_t^s}{e_t}\right]^{\epsilon}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\bar{\mu}_t\phi_t\nu_t. \tag{7}$$

Here, $\bar{\mu}_t \equiv \sum_a s_t^a \mu^a$ is the weighted average of the age-specific taste shifters, with weights given by expenditure shares $s_t^a = \frac{e_t^a N_t^a}{e_t N_t}$. The composite $\phi_t \equiv \frac{1}{N_t}\sum_h^{N_t}\frac{\mu^a}{\bar{\mu}_t}\left[\frac{e_t^h}{e_t}\right]^{1-\epsilon}$ is a measure of the inequality in the economy, weighted by household preferences.[4]

[4]This assumes that within age groups income and idiosyncratic preferences are uncorrelated.

Parameterization We are interested in decomposing changes in expenditure shares into the components due to changes in real income per capita $\frac{e_t}{P_t}$, relative prices $\frac{P_t^g}{P_t^s}$, and changes in the share of expenditures that correspond to the different age groups in the population, $s_t^a \equiv \frac{e_t^a N_t^a}{e_t N_t}$. To conduct this exercise we need to parameterize the income and substitution effects governed by ϵ and γ, as well as the age effects captured by $\bar{\mu}_t$.

We follow Boppart (2014) and proceed in two steps. First we use the cross-section of households from the CES and estimate equation (6) in logs. The estimating equation is:

$$\ln \omega_t^{g,h} = \beta_0 + \beta_1 \ln e_t^h + D^a + \delta_{r,t} + \varepsilon_t^h, \tag{8}$$

where $\beta_0 + \delta_{r,t} = \ln \left(P_t^s\right)^{\epsilon-\gamma} \left(P_t^g\right)^{\gamma}$, $\beta_1 = -\epsilon$, and $\varepsilon_t^h = \ln \mu_t^h$. $D_a = \ln \mu^a$ is an age dummy that captures the taste shifter of the age group relative to an omitted age group. Without loss of generality we normalize $\mu^a = 1$ for age group [25,30). Using these estimates for ϵ and μ^a, we can construct the time series of $\bar{\mu}_t$ and ϕ_t. We can then obtain the price elasticity γ from a regression of equation (7) in logs:

$$\ln \Omega_t^g = b_1 \ln P_t^g + b_2 \ln P_t^s + b_3 X_t + \ln \nu_t, \tag{9}$$

where $X_t \equiv \ln \left(e_t^{-\epsilon} \bar{\mu}_t \phi_t\right)$, $b_1 = \gamma$, and the other coefficients satisfy the restrictions $b_3 = 1$, and $b_2 = \epsilon - b_1$.

Columns 1 and 2 in Table 5 report the results of estimating (8) with OLS. To address measurement error in the CES expenditure data, Columns 3 and 4 report the results of IV estimation with expenditure instrumented by income, as is customary in the literature (see, e.g. Boppart, 2014; Aguiar and Bils, 2015).[5] Table 5 yields an estimate of ϵ of 0.12, which is somewhat smaller than the $\epsilon = 0.2$ found by Boppart (2014).[6] Appendix Table A7 displays the estimates for the age dummies, and shows that our results are robust to using the age of the reference person. Appendix Table A8 shows that the results for ϵ are only slightly different if we consider housing as part of service consumption. The age dummies are relatively large and statistically different from zero, and decrease monotonically with age, indicating that older households spend relatively less on goods after controlling for real income.

Table 6 reports the estimation results for equation (9). To implement it, we construct P_t^g and P_t^s by chain-weighting category-specific price series from NIPA Table 2.4.4, using

[5] We use pre-tax income inclusive of transfers and pension income.

[6] Roughly half of the difference with the Boppart (2014) value is due to the different controls used in that paper vs. ours (our regression includes age decile dummies, which are key for our exercise). The remaining half is mainly due to differences in the classification of CES categories into goods and services (see Table A4).

Table 5: Estimates of equation (8)

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\ln e_t^n$	-0.0476***	-0.0478***	-0.116***	-0.117***
	(0.000642)	(0.000643)	(0.00178)	(0.00179)
Type	OLS	OLS	IV	IV
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,324,874	1,319,092	1,226,096	1,220,472
R^2	0.122	0.125	0.099	0.100

Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table 6: Estimates of equation (9)

	(1)	(2)
Dep. var.: $\ln \Omega_t^g$		
$b_1 = \gamma$	0.143***	0.153***
	(0.0105)	(0.0105)
Age variable	Average	Reference
Observations	35	35
R^2	0.846	0.862

Notes: This table reports the results of estimating equation (9). The outcome variable is aggregate expenditure share on goods. Standard errors in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

the expenditure shares for each category within either goods or services.[7] Our estimate for γ is 0.15. Both γ and ϵ are precisely estimated and significantly different from zero, and satisfy the restriction $\gamma > \epsilon > 0$.

[7]Since the price data are not required to estimate equation (8), our estimates of ϵ and the taste shifters μ_t^a are not affected by potential biases in these data.

Quantitative results Taking logs in equation (7) and rewriting everything in terms of share of consumption on services, we obtain:[8]

$$\hat{\Omega}^s_t \approx -\frac{\Omega^g_{82}}{\Omega^s_{82}} \left\{ \underbrace{\epsilon \left[\hat{P}_t - \hat{e}_t\right]}_{\text{Income}} + \underbrace{\left[\gamma - \epsilon\Omega^g_t\right] \left[\hat{P}^g_t - \hat{P}^s_t\right]}_{\text{Substitution}} + \underbrace{\hat{\mu}_t}_{\text{Aging}} + \underbrace{\hat{\phi}_t + \hat{v}_t}_{\text{Residual}} \right\}, \tag{10}$$

where we used the notation $\hat{x}_t \equiv \ln x_t - \ln x_{82}$ to denote the cumulative log change of a variable between the first year in our sample and time t, and $\hat{P}_t \equiv \left[1 - \Omega^g_t\right] \hat{P}^s_t + \Omega^g_t \hat{P}^g_t$ to denote the log change in the aggregate price index. Equation (10) shows that log-changes in the aggregate expenditure share of goods are additively separable into the effects of changes in 'Income', 'Substitution', 'Aging', and a residual.[9] This decomposition is plotted in Figure 3. The expenditure share in services grew by about 0.2 log points between 1982 and 2016 in the CES data. The contribution of population aging $\hat{\mu}_t$ was nearly 0.05 log points, about a fifth of the total change. About 40% of the total was due to the rise in the relative price of services (labeled 'Substitution'), and another 20% due to the income effect.[10] The residual accounted for remaining roughly 0.05 log points. Appendix Figure A15 shows that the results are unchanged when using the age of the reference person as the household age variable. Appendix Figure A16 shows that the absolute contribution of aging stays unchanged when considering housing as part of service consumption. Appendix B.4 implements an alternative decomposition that isolates purely demographic change, and shows that most of the Aging effect documented in this section is due to demographics rather than the changing age distribution of income.

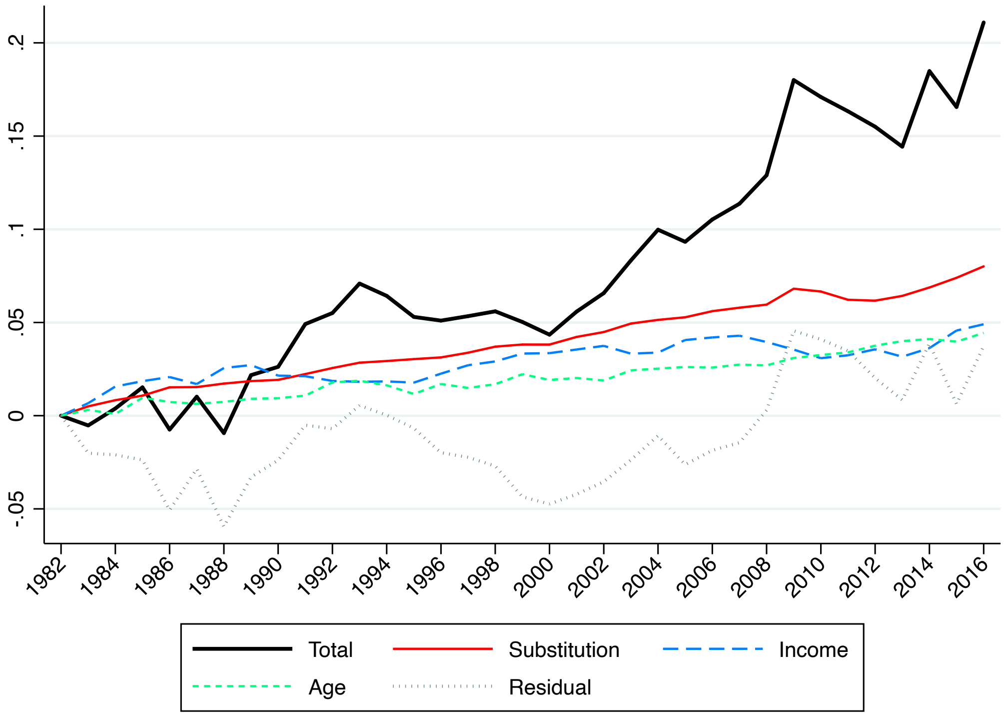
Projected changes in expenditure shares To further illustrate the potential strength of aging as a driver of structural transformation, we compute the contribution of the projected changes in population composition to structural transformation in the future. To

[8]See the Online Appendix B.5 for the derivation. The elasticity of the expenditure share on goods with respect to the relative price of goods to services, $\gamma - \epsilon\Omega^g_t$, ranges from -0.08 to -0.09 depending on year given our estimates of γ and ϵ and the goods expenditure share Ω^g_t in the data. The income elasticity of the goods expenditure share is simply ϵ.

[9]The residual includes both the change in the inequality measure $\hat{\phi}_t$ and the unexplained shifts in taste $\hat{v}_t$. In the data, the changes in the inequality term have a negligible effect on the aggregate service share the throughout the period.

[10]Ignoring the impact of aging on the service expenditure share increases the size of the substitution effect, from 0.08 to 0.13 log points. This is because abstracting from aging increases the estimate of γ by about 20%. This is intuitive: γ is estimated by relating the change in the aggregate service share to the change in prices (equation 9). Our procedure nets out the impact of aging on the service share (X_t), and thus the relative prices have a smaller change in expenditure shares to explain. Thus, if we ignore the impact of aging, a higher γ is needed for the relative price changes to account for the change in expenditure shares. A higher γ, in turn, increases the size of the implied substitution effect.

Figure 3: Accounting for structural change in the US



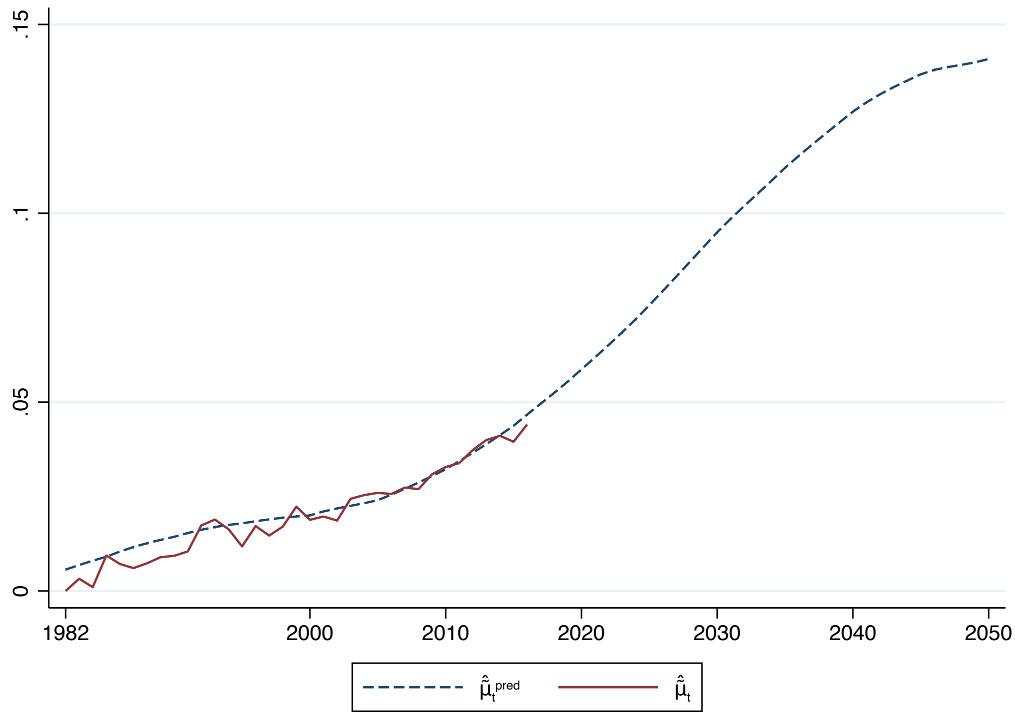
Notes: This figure displays the decomposition (10) for the US from 1982 to 2016.

do this, we use the US population projections to the year 2050 from the World Bank's "Population estimates and projections" database. Because our estimates of the age taste shifters μ^a are at the household level, while the population projections are for population shares by age group, we must convert trends in population into trends in numbers of households. We do this by means of fitting the following regression to map population shares ($PopSh_t^a$) into household age shares:

$$\frac{N_t^a}{N_t} = \beta_1 PopSh_t^a + \beta_2 (PopSh_t^a)^2 + \varepsilon_t \qquad \text{for } t = 1982, ..., 2016. \tag{11}$$

We use a squared term because this specification fits the in-sample data better. Then, for future years we construct $s_t^{a,pred}$ putting together the prediction for the share of age a households among all households $\frac{N_t^a}{N_t} = \widehat{\beta}_1 PopSh_t^a + \widehat{\beta}_2 (PopSh_t^a)^2$ for $t = 2017, ..., 2050$ and $\frac{\bar{e}^a_{2011-16}}{\bar{e}_{2011-16}}$ computed using data for 2011-16. We then construct $\bar{\mu}_t^{pred} = \sum_a s_t^{a,pred} \mu^a$ for t =2017,...,2050. Note that this exercise captures only the contribution of projected population aging on the service share, as it assumes the relative incomes of the different age

Figure 4: Projected change in the service share due to aging in the US



Notes: This figure displays the estimated $\hat{\mu}_t$ from 1982 to 2016, the estimated $\hat{\mu}_t$ from 1982 to 2016 based on the quadratic projection of household numbers on population shares (11), and the projected $\hat{\mu}_t$ for 2017-2050 for the US.

groups stay constant.

Figure 4 reports the results. It turns out that the contribution of aging to structural change over the past 35 years is relatively modest compared to its projected future contribution. The service expenditure share will increase by a further 0.1 log points under the current population aging projections to 2050, even with price of services and real income held constant at today's values. This implies that the service expenditure share in the CES will go from 0.52 in 2016 to 0.57 in 2050. The pace of the increase in the service share accelerates modestly from current rates, before leveling off. This is driven by the faster projected pace of aging between now and the mid-2030s. To evaluate the fit of the population-to-household projection (11), the figure also plots the "prediction" for the structural change over the period for which we do have household data, 1982-2016. The projection fits quite well.

4 Conclusion

This paper documented and quantified the role of population aging in the structural transformation process. Older individuals devote a larger share of their expenditures to services, so the relative size of the service sector grows as the population ages. We document large differences in sectoral expenditure shares across households of different ages in the US CES data, with older households spending relatively more on services. We then use a shift-share decomposition and a quantitative model to show that changes in the US population age accounted for about a fifth of the increase in the consumption share of service expenditures observed between 1982 and 2016. In our quantitative model, the contribution of population aging to the observed structural change in the US during this period is similar to the contribution of real income growth. Projections for the changes in the service expenditure share due to aging in the US suggest that the future impact of aging on structural transformation will be, if anything, larger than its role to date.

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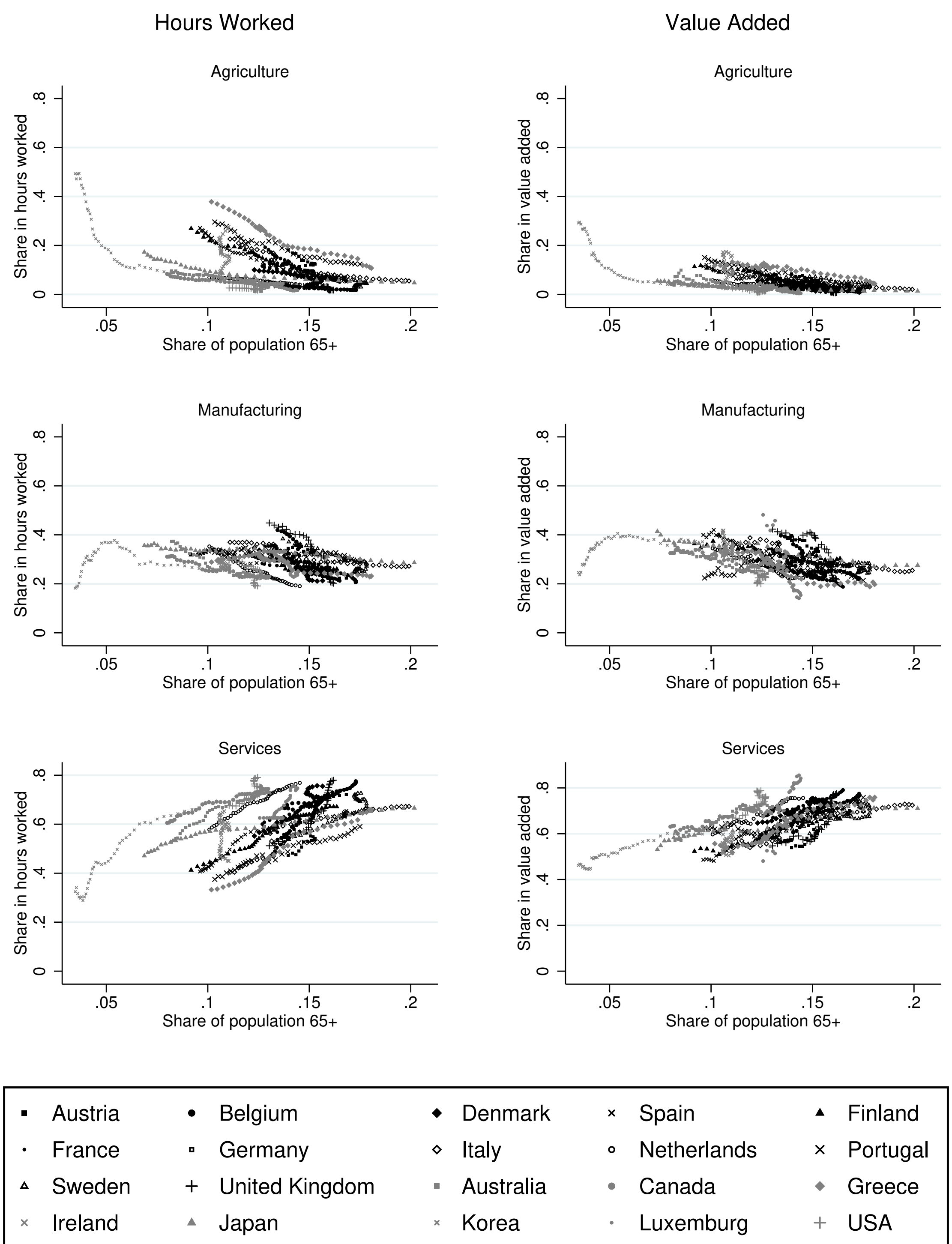
ONLINE APPENDIX
(NOT FOR PUBLICATION)

A Additional cross-country results

A.1 Unconditional patterns

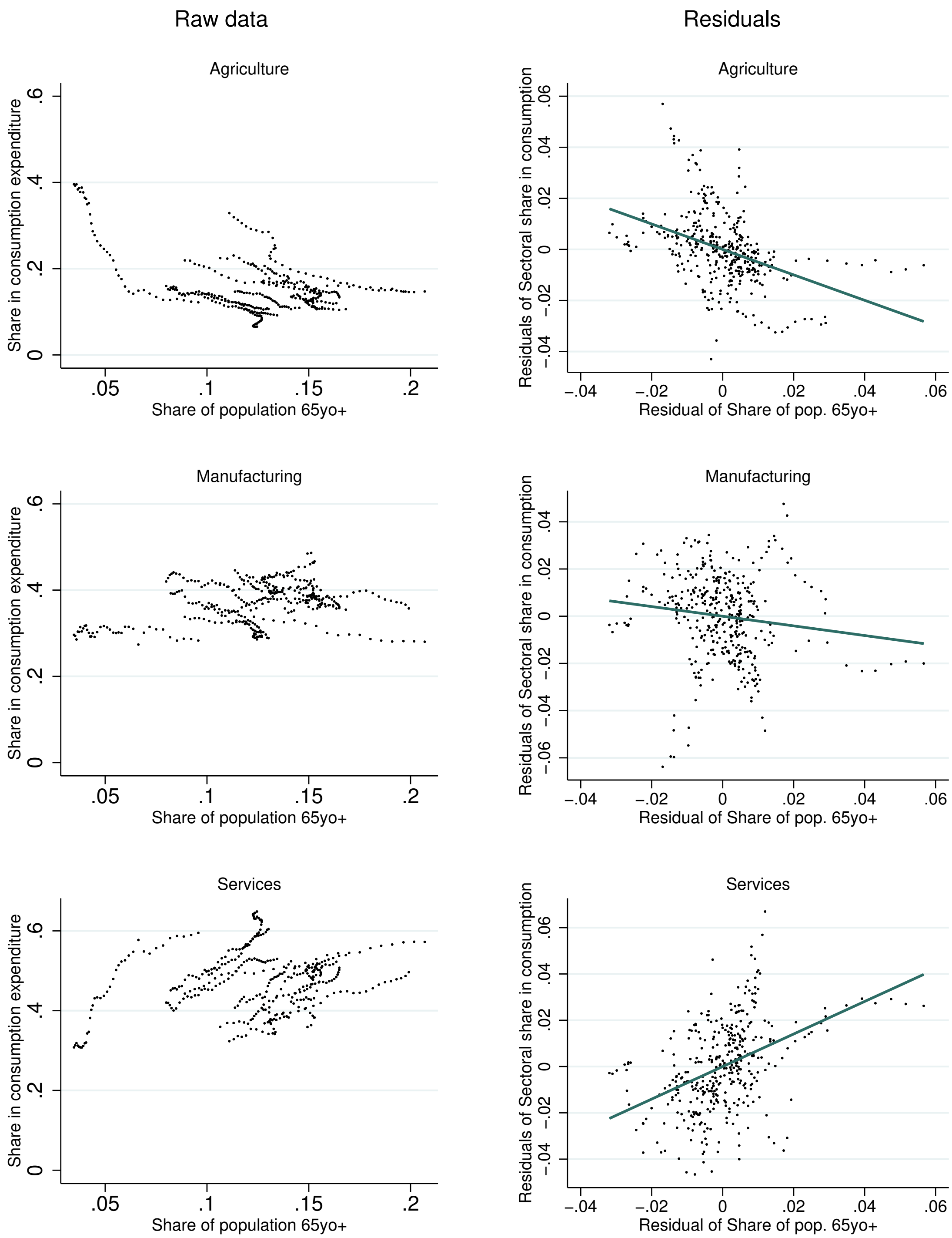
Figure A1 reports the unconditional sectoral shares of hours worked and the share of population over 65, for each country-year in EU KLEMS. The share of hours in Agriculture decreases as population ages, while the share of hours in Services increases. The employment share in Manufacturing is somewhat hump-shaped. The right panel in the figure shows that the same pattern emerges if we use sectoral value added instead of sectoral hours worked shares. The left panel in Figure A2 plots the unconditional sectoral consumption shares against the share of population over 65 for each country-year pair in our sample. These figures indicate that even in raw data, economic activity reallocates towards the service sector as the population ages.

Figure A1: Sectoral shares of employment and value added



Notes: Each dot represents a country-year. The x-axis reports the share of the population that is 65 and over (source: WDI). The y-axis reports the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) using data from EU KLEMS.

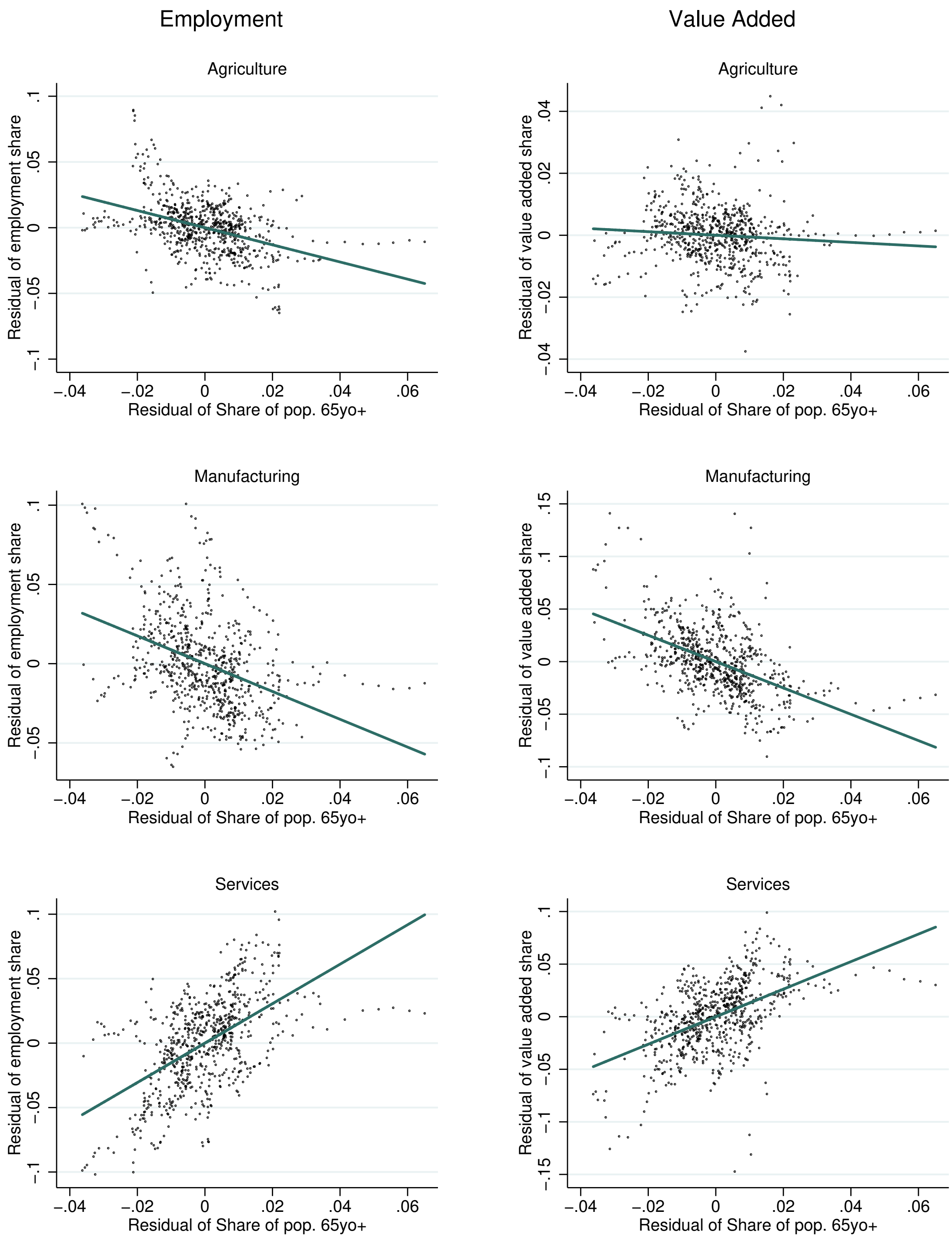
Figure A2: Sectoral consumption shares



Notes: Each dot represents a country-year. The x-axis reports the actual (left panel) and the residualized (right panel) share of the population that is 65 and over. The y-axis reports the sectoral share in actual (left panel) and the residualized (right panel) sectoral shares in consumption using data from OECD.

Controlling for income: The patterns that underlie Tables 1-2 can be visualized in Figure A3 and the right panel of Figure A2. The y-axis plots the residuals of the regressions of the employment and value added shares on the log of GDP per capita, log of GDP per capita squared and country fixed effects. The x-axis shows the residuals of the share of population that is over 65 on those same variables. The changes in sectoral shares that are orthogonal to the changes in income per capita are strongly correlated to the changes in population age that are orthogonal to income per capita. The figures show that consumption in Agriculture and Manufacturing products decline with population age, while the share of Service consumption increases with population age, after controlling for income and country effects.

Figure A3: Residualized sectoral shares of employment and value added

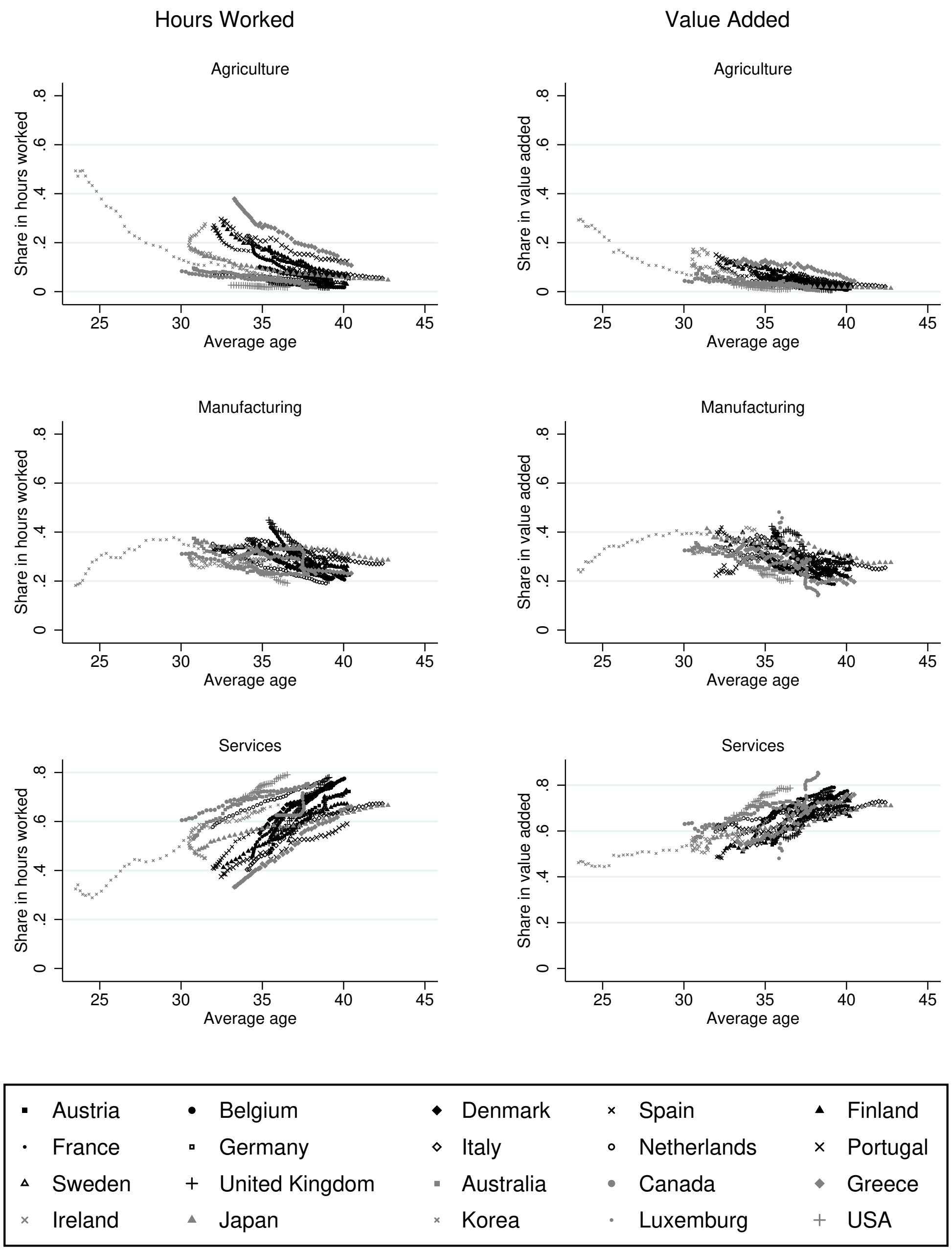


Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over on GDP per capita, GDP per capita squared, and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) on GDP per capita, GDP per capita squared, and country fixed effects. Data sources are the same as in Figure A1.

A.2 Using average age

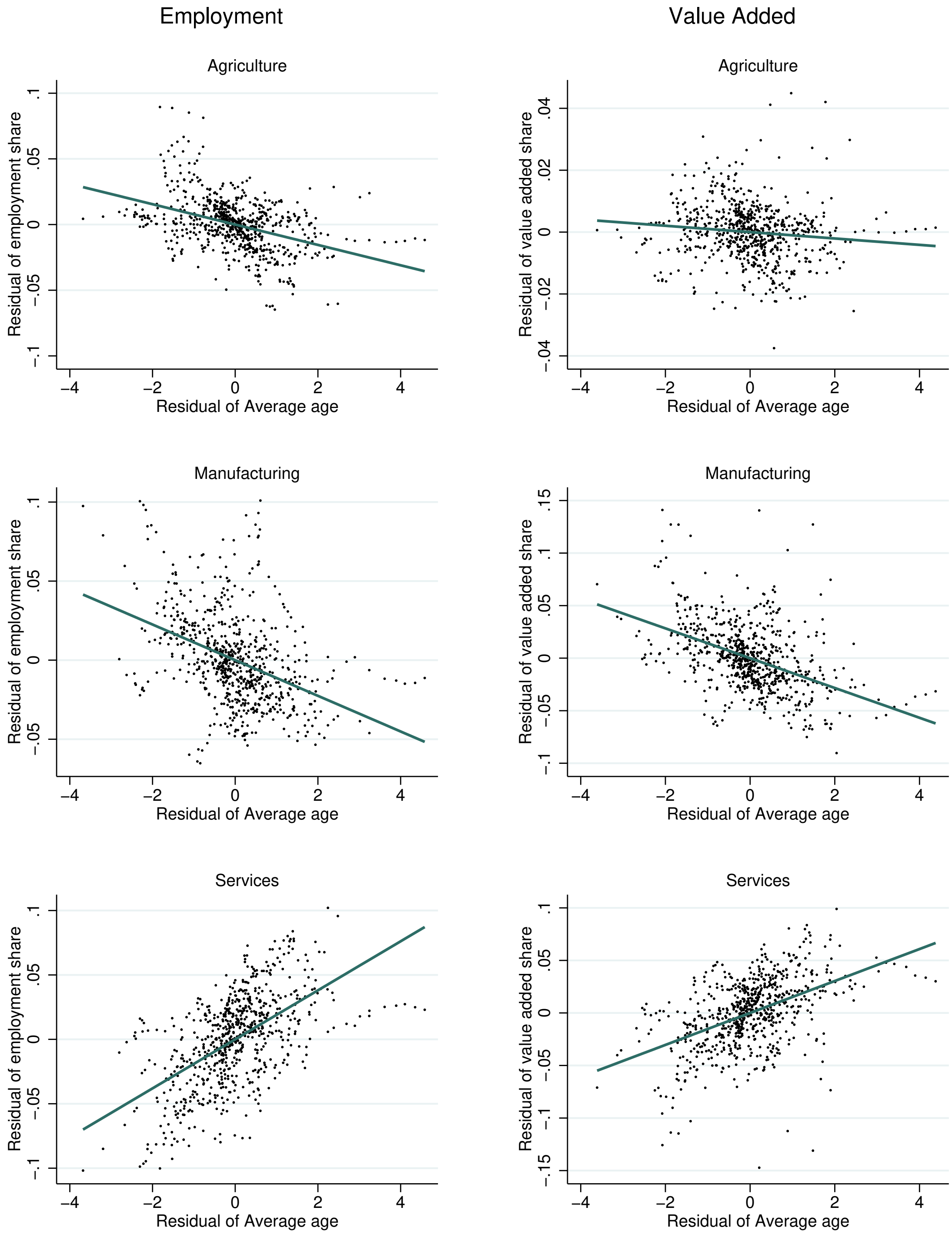
As an alternative measure of aging, we use the average age in the country, computed from the World Bank's "Population estimates and projection" database. This database divides a country's population into 5-year age brackets. To compute the average age, we multiply the midpoint of each bracket (e.g. 2 in the 0-4 years old bracket) times its population, then add across age groups, and finally divide this by the total population. Appendix Figures A4, A5, and A6 show that the patterns documented in the main text and in this Appendix persist if we use the average age in the population instead of the share of population over 65 as our age measure.

Figure A4: Sectoral shares of employment and value added



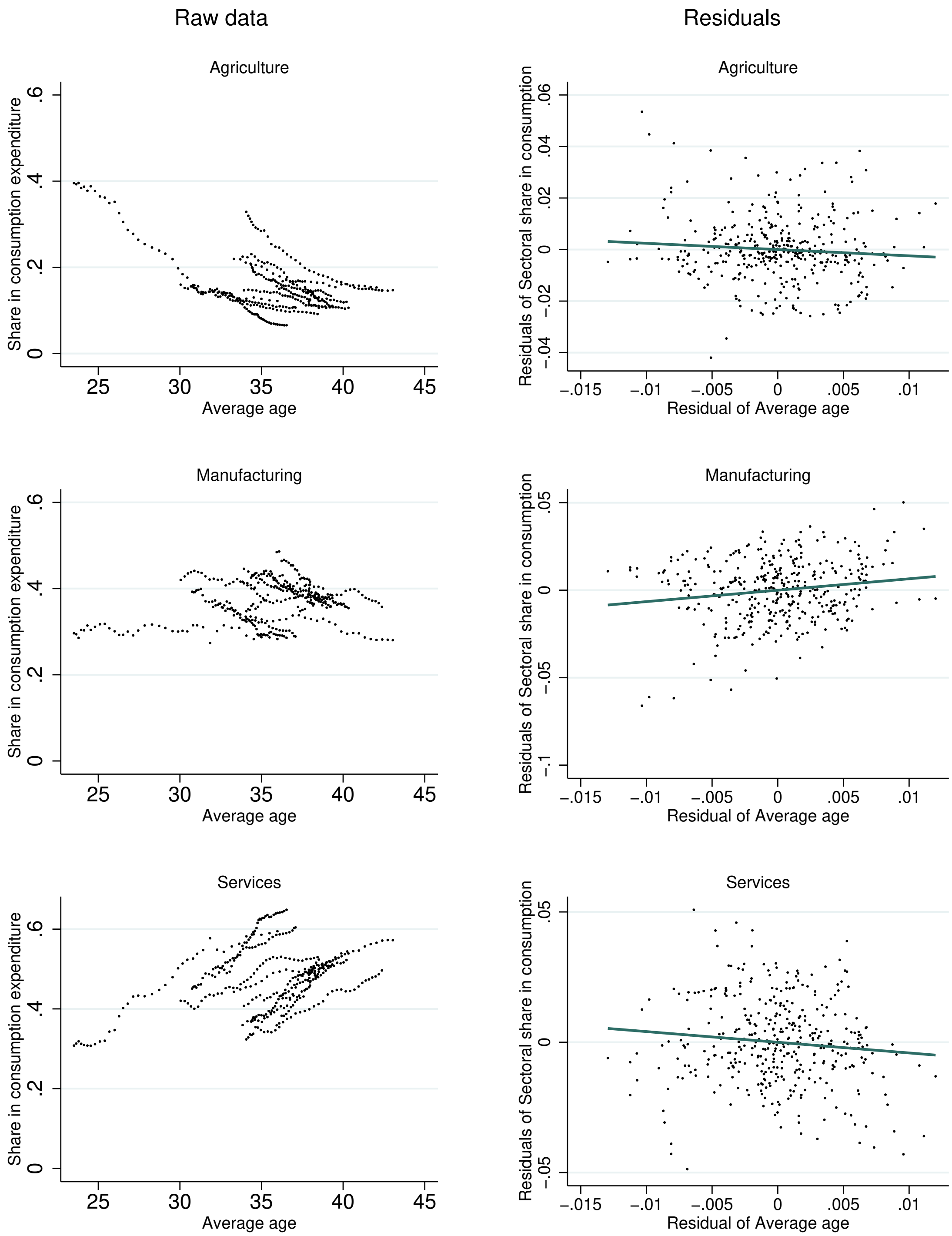
Notes: Each dot represents a country-year. The x-axis reports the average age in the population (source: WDI). The y-axis reports the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) using data from EU KLEMS.

Figure A5: Residualized sectoral shares of employment and value added



Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the average age in the population on GDP per capita, GDP per capita squared, and country fixed-effects. The y-axis reports the residual of a regression of the sectoral share in hours worked (left panel) and the sectoral shares in value added (right panel) on GDP per capita, GDP per capita squared, and country fixed-effects. Data sources are the same as in Figure A1.

Figure A6: Sectoral consumption shares



Notes: Each dot represents a country-year. The x-axis reports the actual (left panel) and the residualized (right panel) average age in the population. The y-axis reports the sectoral share in actual (left panel) and the residualized (right panel) sectoral shares in consumption using data from OECD.

A.3 Additional controls

Table A1 presents the main results for each of the three main outcome variables, controlling for (i) trade openness, (ii) investment/GDP ratio; (iii) government expenditures as a share of GDP, and (iv) the relative price of services. We take the controls (i)-(iii) from the World Development Indicators. The relative price of services was computed by aggregating sectorial price indexes from EU KLEMS. Sectors 15 to 37 in KLEMS were aggregated into Goods, and sectors G, H, 60 to 64, J, 70 to 74, L, M, N, O, P, Q were aggregated into Services. Following Herrendorf et al. (2013) and Bonadio et al. (2021), the indexes were aggregated using a cyclical expansion procedure. In particular, let Y_{it}, Q_{it}, and P_{it} denote the nominal output, the quantity index, and the price index for a sub-sector i at time t provided by KLEMS. Aggregate quantity indexes for Goods and for Services were computed as:

$$Q_t^j \equiv \sqrt{\frac{\sum_{i \in j} P_{it} Q_{it-1}}{\sum_{i \in j} Y_{it-1}} \frac{\sum_{i \in j} Y_{it}}{\sum_{i \in j} P_{it-1} Q_{it}}},$$

and the corresponding price indexes were computed as $P_t^j \equiv \sum_{i \in j} Y_{it} / Q_t^j$. We note that, since our regressions include country fixed effects, the price indexes are sufficient for the purposes of controlling for the within-country changes in the relative price of services over time. The coefficients on the age variable in these alternative specifications are similar to our baseline and statistically significant.

Table A1: Population aging and the services share in hours worked, value added and consumption

	Hours worked				Value added				Consumption			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$
Share of pop 65+	1.520***	0.827*	1.024*	1.488***	1.278***	0.790**	0.691**	1.263***	0.690***	0.239	0.512*	0.576**
	(0.479)	(0.434)	(0.511)	(0.490)	(0.348)	(0.364)	(0.294)	(0.387)	(0.204)	(0.168)	(0.230)	(0.209)
Log GDP p.c.	-0.023	0.247	-0.067	-0.016	-0.890***	-0.638***	-0.901***	-0.837***	-0.200	-0.091	-0.328**	-0.373**
	(0.286)	(0.171)	(0.259)	(0.231)	(0.221)	(0.140)	(0.127)	(0.157)	(0.148)	(0.113)	(0.143)	(0.132)
(Log GDP p.c.)^2	0.010	-0.004	0.012	0.007	0.053***	0.040***	0.054***	0.047***	0.019*	0.014*	0.026**	0.025***
	(0.016)	(0.009)	(0.014)	(0.013)	(0.013)	(0.008)	(0.007)	(0.009)	(0.009)	(0.007)	(0.008)	(0.007)
Trade/GDP	-0.000				-0.000				0.000			
	(0.000)				(0.000)				(0.000)			
Investment/GDP		-0.006***				-0.005***				-0.005***		
		(0.001)				(0.001)				(0.001)		
Goverment/GDP			0.007**				0.009***				0.004*	
			(0.003)				(0.003)				(0.002)	
P_t^s / P_t^g				0.053*				0.058**				0.086***
				(0.030)				(0.023)				(0.026)
Observations	707	707	707	707	707	707	707	707	377	377	377	369
R^2	0.924	0.953	0.934	0.929	0.874	0.902	0.901	0.884	0.949	0.964	0.952	0.960

Notes: This table reports the results of estimating equation (1) with additional controls. The outcome variables are hours worked, value added and consumption shares in services (*Ser*). Population age is proxied by the share of population 65 years or older. Additional controls Trade/GDP, Investment/GDP and Government/GDP come from WDI. Trade/GDP is the sum of imports and exports as a share of GPD. Control variable P_t^s / P_t^g is the ratio of the price of services to manufacturing goods in EU-KLEMS. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

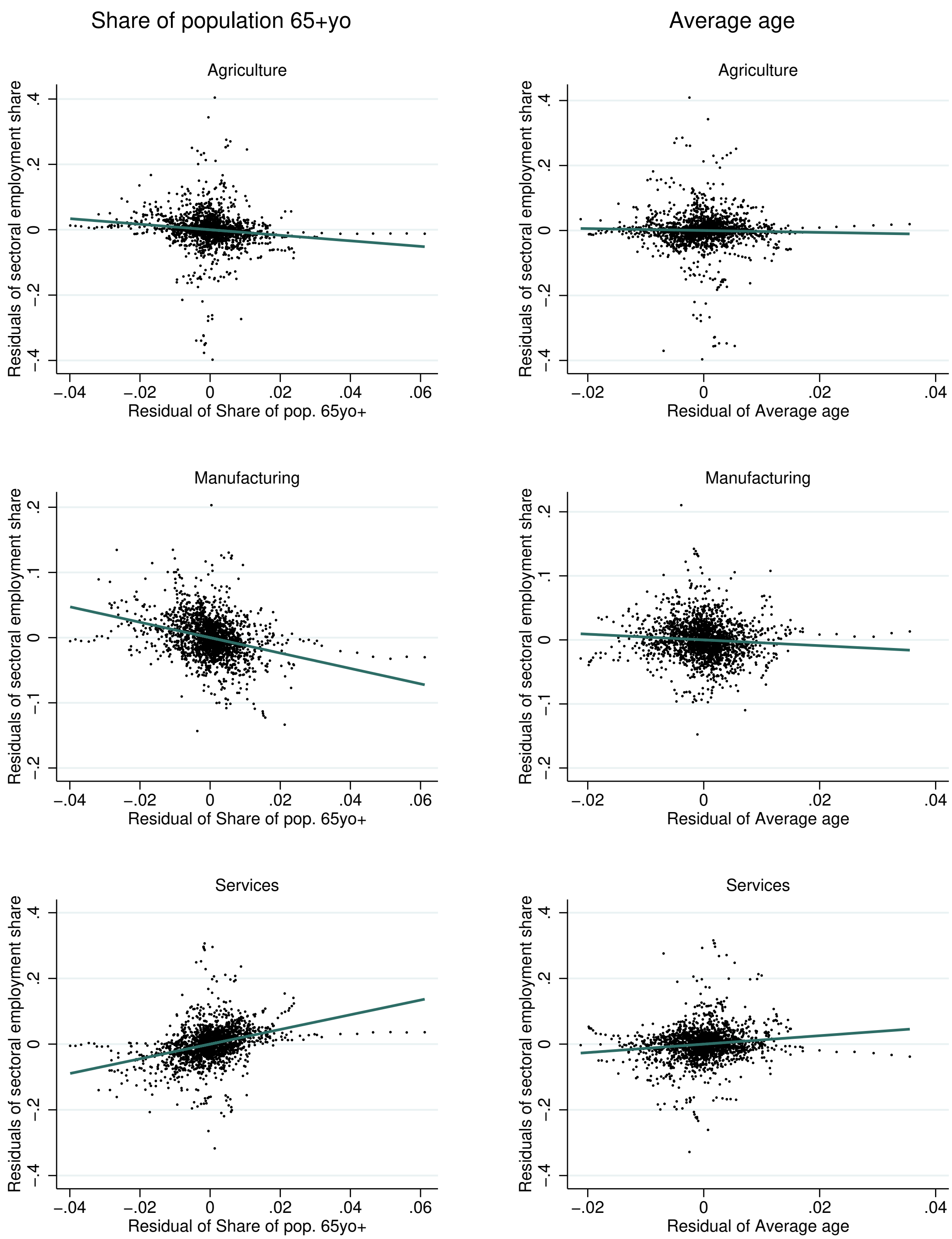
A.4 Evidence from the WDI and the UN Statistics Division

This section complements the evidence from Section 2.1 using employment data from the WDI and value-added data from the UN. Relative to the data presented in the main text, these sources cover a much broader sample of both developed and developing countries. On the other hand, unlike the EU-KLEMS data, the WDI only reports number of employed persons as opposed to number of hours worked, and the value-added data from the UN are obtained from country-specific sources that are not necessarily harmonized. The WDI yields an unbalanced sample of 157 countries covering 1980-2007, while the UN data cover 188 countries over 1970-2007.

We replicate the fact reported in Section 2.1 using these alternative data. Table A2 and Figure A7 summarize the results from a regression analogous to Equation (1) that is estimated on the WDI data. They show that, after controlling for income, there is a clear negative relation between population age and the employment shares in Agriculture and Manufacturing, and a strong positive relation between population age and the share of employment in the Service sector. These relations are observed for each of our population age variables.

Figure A8 and Table A3 corroborate that the same patterns described in Section 2.1 are also present in the value-added data from the UN. After controlling for income, there is a clear negative relation between population age and the employment shares in Agriculture and Manufacturing, and a strong positive relation between population age and the share of employment in the service sector.

Figure A7: Residualized sectoral employment shares: WDI data



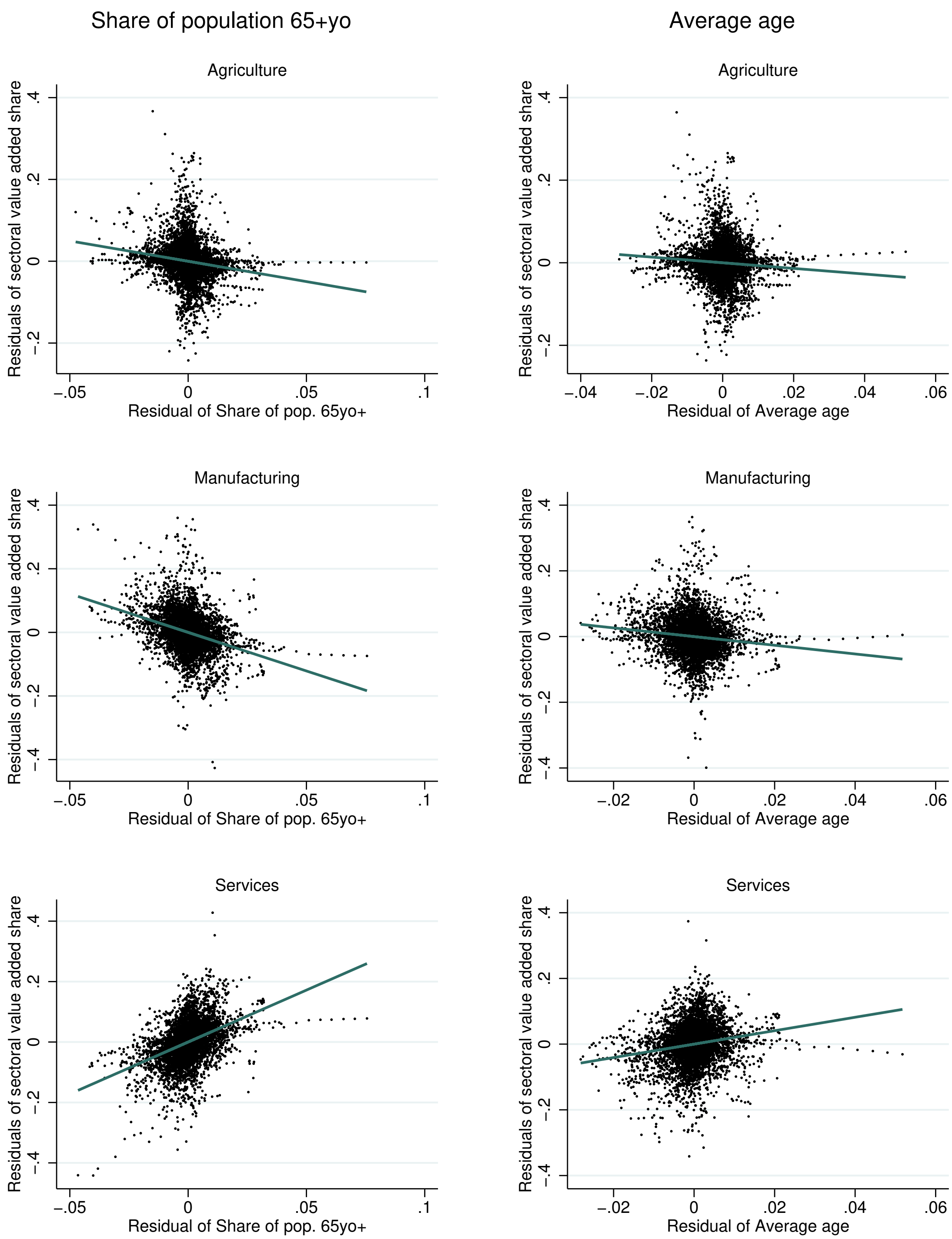
Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over (left panel) or the average age of the population (right panel) on GDP per capita, GDP per capita squared, and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in employment on GDP per capita, GDP per capita squared, and country fixed effects.

Table A2: Population aging and the services share in employment: WDI data

	(1)	(2)	(3)	(4)	(5)	(6)
	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$
Average age	-0.0136***	-0.00807**	-0.0103***	-0.0110***	0.0249***	0.0189***
	(0.00232)	(0.00348)	(0.00239)	(0.00280)	(0.00240)	(0.00367)
Log GDP per capita		-0.404**		0.771***		-0.304**
		(0.155)		(0.167)		(0.153)
(Log GDP per capita)^2		0.0189**		-0.0416***		0.0194**
		(0.00830)		(0.00932)		(0.00843)
Observations	2206	2029	2214	2037	2214	2037
R^2	0.921	0.919	0.805	0.854	0.904	0.898

Notes: This table reports the results of estimating equation (1). The outcome variables are employment shares in agriculture (*Agr*), manufacturing (*Man*) and services (*Ser*). Population age is proxied by the average age. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Figure A8: Residualized sectoral value-added shares: UN data



Notes: Each dot represents a country-year. The x-axis reports the residual of a regression of the share of the population that is 65 and over (left panel) or the average age of the population (right panel) on GDP per capita and country fixed effects. The y-axis reports the residual of a regression of the sectoral share in value added (second panel) on GDP per capita and country fixed effects.

Table A3: Population aging and the services share in value-added: UN data

	(1)	(2)	(3)	(4)	(5)	(6)
	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Agr}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Man}$	$\omega_{i,t}^{Ser}$	$\omega_{i,t}^{Ser}$
Average age	-0.0117***	-0.00570***	-0.00648***	-0.0153***	0.0180***	0.0210***
	(0.00136)	(0.00143)	(0.00166)	(0.00267)	(0.00163)	(0.00282)
Log GDP pc		-0.380***		0.276***		0.113
		(0.0642)		(0.0783)		(0.0910)
(Log GDP pc)^2		0.0181***		-0.0105**		-0.00822
		(0.00360)		(0.00514)		(0.00563)
Observations	6509	6156	6547	6194	6547	6194
R^2	0.880	0.908	0.778	0.822	0.829	0.826

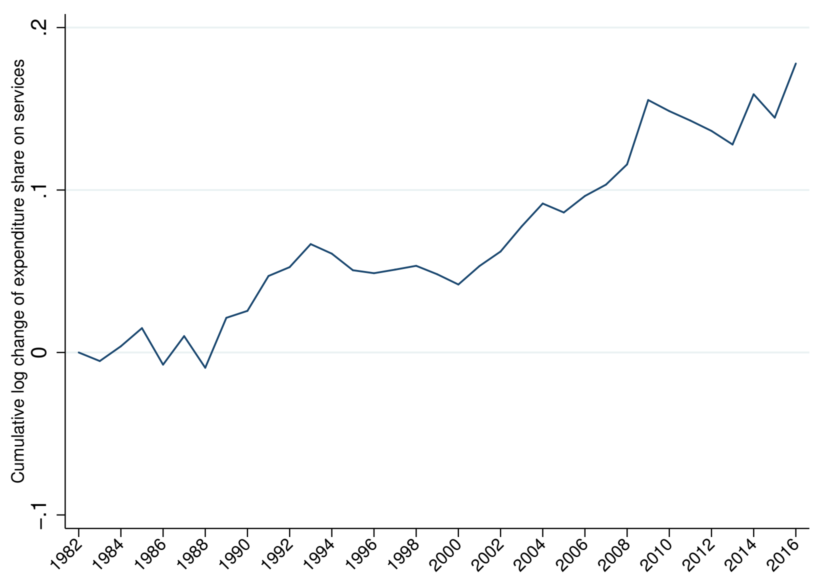
Notes: This table reports the results of estimating equation (1). The outcome variables are value added shares in agriculture (*Agr*), manufacturing (*Man*) and services (*Ser*). Population age is proxied by the average age. All specifications include country fixed effects. Standard errors clustered at the country level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

B Additional results, household-level data and model

B.1 Additional tables and figures, CES

Figure A9 plots the cumulative change in the aggregate expenditure share on services in the CES data. Consistent with the aggregate evidence on structural transformation, the service expenditure share rises in the CES, by about 0.18 log points over this period. Appendix Table A4 reports the trends in broad service expenditure categories. The rise in the healthcare is the main, but not the only, driver of the upward trend in the service expenditure. Other categories showing substantial proportional increases are Cash Contributions and Education.

Figure A9: Service consumption in the CES



Notes: This figure displays the cumulative log change in the aggregate expenditure share on services in the CES.

Table A4: Expenditure shares on goods and services

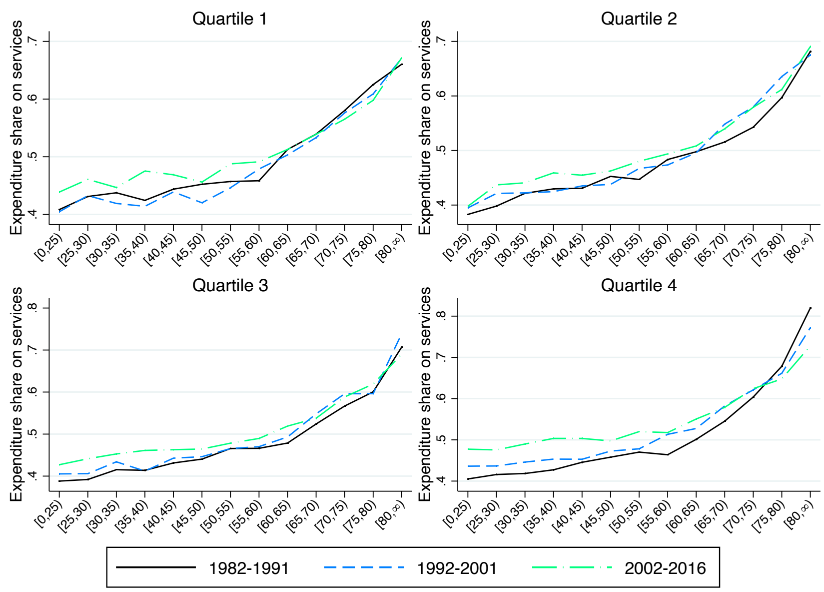
	Baseline			Baseline w/ housing			All expenditure in CES		
	82-91	92-01	02-16	82-91	92-01	02-16	82-91	92-01	02-16
Goods	*51.0*	*49.8*	*47.7*	*40.5*	*38.1*	*35.4*	*37.0*	*34.6*	*31.6*
Food at home	15.6	15.1	14.7	12.4	11.5	10.9	11.4	10.6	9.8
Vehicle purchasing, leasing	12.0	13.6	12.0	9.6	10.4	8.9	8.7	9.4	7.9
Gas	5.4	4.3	6.3	4.3	3.2	4.7	3.9	2.9	4.2
Entertainment equipment	4.1	4.7	5.3	3.2	3.6	3.9	2.9	3.3	3.5
Appliances	2.7	2.8	2.3	2.1	2.2	1.7	2.0	2.0	1.5
Men's and women's clothing	3.9	3.1	1.9	3.1	2.4	1.4	2.8	2.2	1.3
Furnitures and Fixtures	2.4	2.0	1.7	1.9	1.5	1.3	1.8	1.4	1.1
Alcoholic beverages	1.5	1.2	1.2	1.2	0.9	0.9	1.1	0.8	0.8
Shoes and other apparel	1.5	1.2	0.9	1.2	0.9	0.7	1.1	0.9	0.6
Tobacco	1.3	1.1	1.0	1.0	0.8	0.7	0.9	0.7	0.6
Children's clothing	0.6	0.6	0.4	0.5	0.5	0.3	0.4	0.4	0.3
Personal care goods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Services	*49.0*	*50.2*	*52.3*	*59.5*	*61.9*	*64.6*	*63.0*	*65.4*	*68.4*
Health	9.1	10.1	12.1	7.2	7.7	9.0	6.8	7.2	8.2
Utilities	11.0	10.7	11.6	8.8	8.2	8.6	8.1	7.5	7.8
Cash contributions	4.9	5.1	5.7	3.9	3.9	4.3	3.7	3.7	3.9
Car maint, repairs	5.4	5.9	5.2	4.3	4.5	3.9	3.9	4.1	3.5
Food away from home	6.4	5.9	5.0	5.1	4.5	3.7	4.6	4.1	3.3
Domestic services	4.2	4.1	4.2	3.3	3.2	3.1	3.1	2.9	2.8
Education	1.4	1.7	2.7	1.1	1.3	2.0	1.0	1.2	1.8
Entertainment fees, adm., read.	2.9	3.0	2.5	2.3	2.3	1.8	2.1	2.1	1.6
Public transport	1.9	2.0	1.8	1.5	1.5	1.3	1.4	1.4	1.2
Personal care services	1.4	1.3	1.0	1.1	1.0	0.8	1.0	0.9	0.7
Childcare	0.3	0.4	0.5	0.3	0.3	0.4	0.2	0.3	0.3
Housing	.	.	.	20.6	23.5	25.7	18.9	21.5	23.0
Personal insurance	.	.	.	.	.	.	1.4	1.3	0.8
Pensions	.	.	.	.	.	.	6.7	7.3	9.4

Notes: This table reports the aggregate expenditure shares on broad categories of goods and services, in the three decades separately, in the baseline using the CES, including housing and using the entire Interview dataset in the CES.

Figure A10 plots the age-service expenditure share relationships separately for each quartile of the income distribution. It is clear that the relationship is about equally strong within broad income groups.

Structural change within the service sector The rise in service expenditures has been concentrated in categories that are disproportionally consumed by older households. Figure A11 divides service categories into two groups: one for the categories that are disproportionally consumed by the old (Health, Utilities, and Domestic Services), and one for the remaining categories. The figure shows a dramatic increase in the aggregate expenditure share for Health, Utilities, and Domestic Services, the combined expenditure share in these categories goes from 21 to over 28 percent over our period. In contrast, there is no change in the expenditure share in the remaining service categories. Figure A20 shows that a similar pattern emerges in the Personal Consumption Expenditure data from the

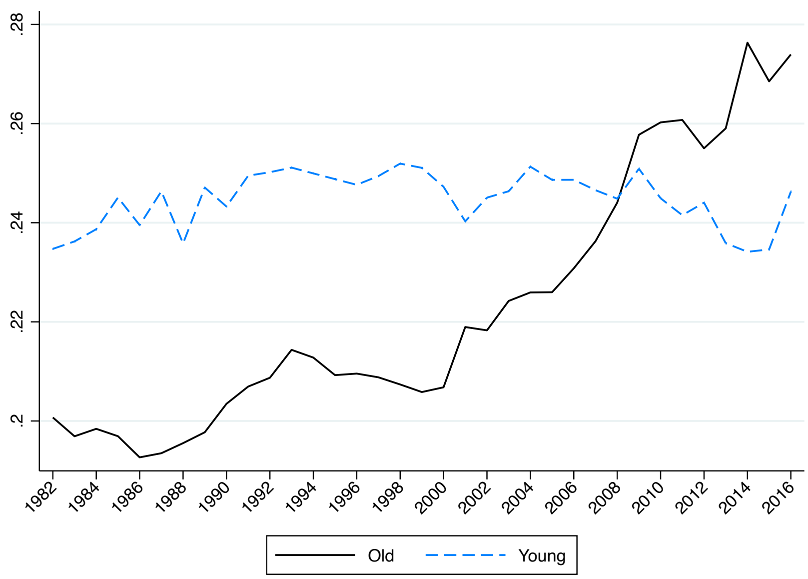
Figure A10: Service consumption by average age of household members and income



Notes: This figure displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods, and each income quartile.

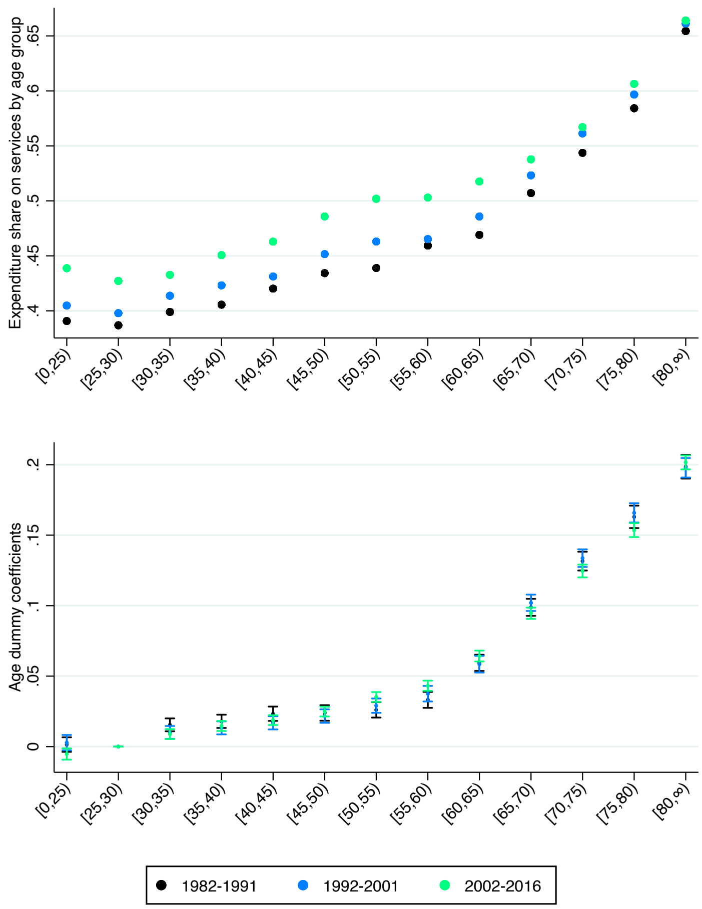
BEA: the increase in service consumption is concentrated among those categories that are disproportionally consumed by the old.

Figure A11: Evolution of expenditure shares on service categories in the CES



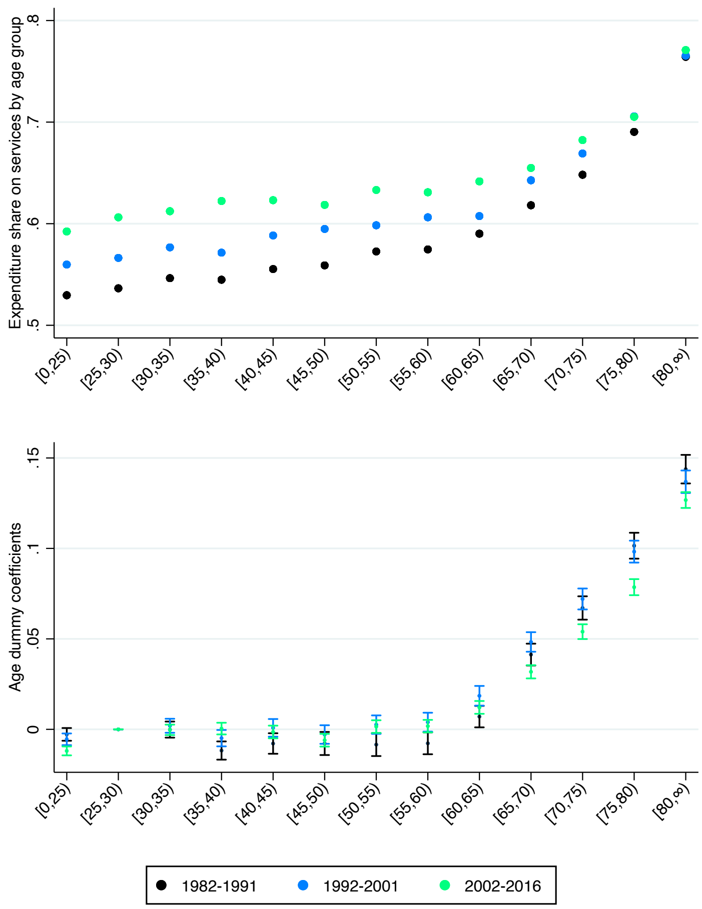
Notes: 'Old' displays the aggregate expenditure share in the CES on categories that are disproportionally consumed by the old: Health, Utilities, and Domestic Services. 'Young' displays the expenditure share on the remaining service categories.

Figure A12: Service consumption by age of the reference person



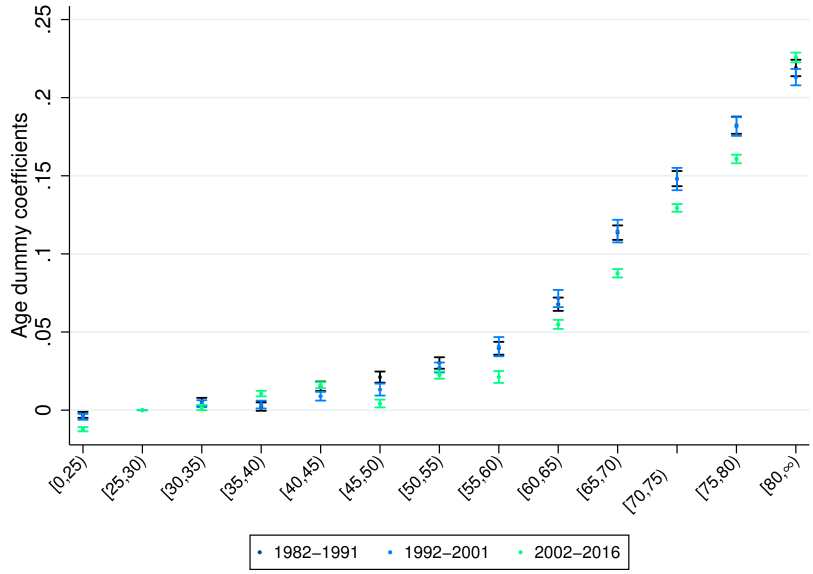
Notes: The top panel displays the average household-level expenditure shares on services in the CES by age group according to the age of the reference person (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Figure A13: Service consumption with housing by average age of household members



Notes: The top panel displays the average household-level expenditure shares on services in the CES by age group (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level. Housing is included in expenditures.

Figure A14: Age dummies (controlling for income decile), including age-specific price indices



Notes: Each dot represents the point estimate of the age dummies in modified Equation (2) for a particular decade in the CES data. The modified equation includes age-specific price indices as controls. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Table A6: Share of out-of-pocket expenses in total personal healthcare expenses, NHES

Age group	2002	2014
0-44	0.144	0.112
45-64	0.164	0.121
65+	0.173	0.153

Notes: This table reports the ratios of out-of-pocket to total personal healthcare expenditures by broad age group from the National Health Expenditure Survey.

Table A5: Population aging and changes in the services share, including housing

Panel A: Expenditure shares across the age distribution

	Pop 1982	s^a_{1982}	$\omega^{s,a}_{1982}$	Pop 2016	s^a_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	31.6	51.8	20.4	20.0	61.2
25-30	13.5	16.1	52.1	11.4	12.0	61.9
30-35	9.4	11.3	54.3	9.4	10.8	63.4
35-40	6.2	7.5	53.9	7.1	7.9	62.7
40-45	4.6	5.3	55.2	5.9	6.5	65.5
45-50	3.6	3.9	55.6	5.2	5.5	63.7
50-55	3.8	3.9	56.0	6.1	6.1	63.7
55-60	5.1	4.8	57.2	6.7	6.8	63.6
60-65	5.7	5.2	60.1	7.5	7.5	67.7
65-70	5.9	4.5	62.1	6.8	6.2	67.4
70-75	4.3	2.8	66.9	5.1	4.4	67.4
75-80	3.3	1.8	68.0	3.4	2.7	70.2
80+	2.9	1.3	76.5	5.0	3.5	78.6

Panel B: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.0811	86.3	0.0834	88.7
Between	0.0129	13.7	0.0107	11.3
Total	0.0940	100	0.0940	100

Notes: In Panel A, ’Pop’ reports the share of the population in each age group, and s^a_t and ω^a_t are defined as in Equation (4). Panel B reports the results of the decomposition in equation (4). ’Average’ uses the average age across all household member as the age of the household. ’Reference’ uses the age of the head in the household. Housing is included in expenditures.

B.2 Additional tables and figures for Section 3.2

Table A7: Estimates of equation (8) for different age measures

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\ln e_t^n$	-0.116***	-0.117***	-0.118***	-0.119***
	(0.00178)	(0.00179)	(0.00191)	(0.00191)
$D^{[0,25)}$	0.0139***	0.0141***	-0.0557***	-0.0555***
	(0.00206)	(0.00206)	(0.00330)	(0.00331)
$D^{[30,35)}$	-0.0150***	-0.0155***	0.000930	0.000256
	(0.00254)	(0.00254)	(0.00275)	(0.00275)
$D^{[35,40)}$	-0.0258***	-0.0266***	0.00153	0.000858
	(0.00283)	(0.00283)	(0.00278)	(0.00279)
$D^{[40,45)}$	-0.0454***	-0.0461***	-0.00562**	-0.00629**
	(0.00313)	(0.00314)	(0.00286)	(0.00286)
$D^{[45,50)}$	-0.0562***	-0.0575***	-0.0264***	-0.0270***
	(0.00325)	(0.00326)	(0.00292)	(0.00293)
$D^{[50,55)}$	-0.0932***	-0.0930***	-0.0594***	-0.0597***
	(0.00332)	(0.00333)	(0.00302)	(0.00302)
$D^{[55,60)}$	-0.118***	-0.118***	-0.0879***	-0.0888***
	(0.00326)	(0.00326)	(0.00316)	(0.00317)
$D^{[60,65)}$	-0.172***	-0.173***	-0.142***	-0.142***
	(0.00338)	(0.00338)	(0.00335)	(0.00336)
$D^{[65,70)}$	-0.255***	-0.255***	-0.224***	-0.225***
	(0.00360)	(0.00360)	(0.00349)	(0.00349)
$D^{[70,75)}$	-0.340***	-0.341***	-0.309***	-0.310***
	(0.00402)	(0.00403)	(0.00397)	(0.00397)
$D^{[75,80)}$	-0.435***	-0.436***	-0.406***	-0.407***
	(0.00483)	(0.00482)	(0.00462)	(0.00462)
$D^{[80,\infty)}$	-0.592***	-0.592***	-0.551***	-0.552***
	(0.00548)	(0.00548)	(0.00508)	(0.00508)
Age variable	Average	Average	Reference	Reference
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,226,096	1,220,472	1,226,096	1,220,472
R^2	0.099	0.100	0.085	0.087

Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table A8: Estimates of equation (8) with housing

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\ln e_t^n$	-0.0906***	-0.0869***	-0.0893***	-0.0847***
	(0.00218)	(0.00219)	(0.00238)	(0.00239)
$D^{[0,25)}$	0.0344***	0.0345***	-0.00426	-0.000668
	(0.00254)	(0.00253)	(0.00397)	(0.00396)
$D^{[30,35)}$	-0.0152***	-0.0151***	-0.000360	-0.00143
	(0.00320)	(0.00318)	(0.00343)	(0.00341)
$D^{[35,40)}$	-0.0155***	-0.0157***	0.00620*	0.00525
	(0.00358)	(0.00355)	(0.00348)	(0.00347)
$D^{[40,45)}$	-0.0370***	-0.0366***	0.0139***	0.0126***
	(0.00394)	(0.00393)	(0.00354)	(0.00352)
$D^{[45,50)}$	-0.0360***	-0.0372***	0.00962***	0.00802**
	(0.00404)	(0.00404)	(0.00361)	(0.00360)
$D^{[50,55)}$	-0.0684***	-0.0692***	-0.0132***	-0.0143***
	(0.00408)	(0.00408)	(0.00371)	(0.00370)
$D^{[55,60)}$	-0.0723***	-0.0734***	-0.0263***	-0.0283***
	(0.00397)	(0.00396)	(0.00384)	(0.00383)
$D^{[60,65)}$	-0.106***	-0.108***	-0.0617***	-0.0630***
	(0.00401)	(0.00400)	(0.00399)	(0.00398)
$D^{[65,70)}$	-0.178***	-0.178***	-0.128***	-0.128***
	(0.00414)	(0.00414)	(0.00408)	(0.00408)
$D^{[70,75)}$	-0.251***	-0.252***	-0.202***	-0.203***
	(0.00453)	(0.00455)	(0.00452)	(0.00452)
$D^{[75,80)}$	-0.351***	-0.351***	-0.299***	-0.299***
	(0.00531)	(0.00532)	(0.00512)	(0.00513)
$D^{[80,\infty)}$	-0.560***	-0.558***	-0.487***	-0.484***
	(0.00657)	(0.00659)	(0.00612)	(0.00614)
Age variable	Average	Average	Reference	Reference
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,226,096	1,220,472	1,226,096	1,220,472
R^2	0.078	0.084	0.064	0.070

Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods including housing. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%. Housing is included in expenditures.

Figure A15: Accounting for structural change in the US, using reference person's age

Notes: This figure displays the decomposition (10) for the US from 1982 to 2016, using the age of the reference person as the age variable.

Figure A16: Accounting for structural change in the US, using housing as service

Notes: This figure displays the decomposition (10) for the US from 1982 to 2016, using the average age of members as the age variable and including housing as part of service consumption.

B.3 Rescaling CES expenditure data to aggregate data

Rescaling procedure This section rescales the expenditure data in the Consumption Expenditure Survey to match the aggregate Personal Consumption Expenditure (PCE) shares reported by the BEA. In principle, these data need not coincide, since they are collected from different sources that use very different methodologies.[11] After concording the expenditure categories in the CES to PCE items in the BEA data, we compute total expenditures in the CES, $e_t^{j,CES}$, for each category j and year t. We then create the scaling factor for each category that reflects the discrepancy in the aggregate expenditure between the CES and the BEA: $X_t^j = e_t^{j,BEA} / e_t^{j,CES}$. Then, we rescale the consumption expenditure of each household by this factor: $e_t^{j,h} = e_t^{j,h,CES} \times X_t^j$. In this way, the aggregate expenditure on each category in each year in the CES in the rescaled data match the BEA aggregates in every category and year.

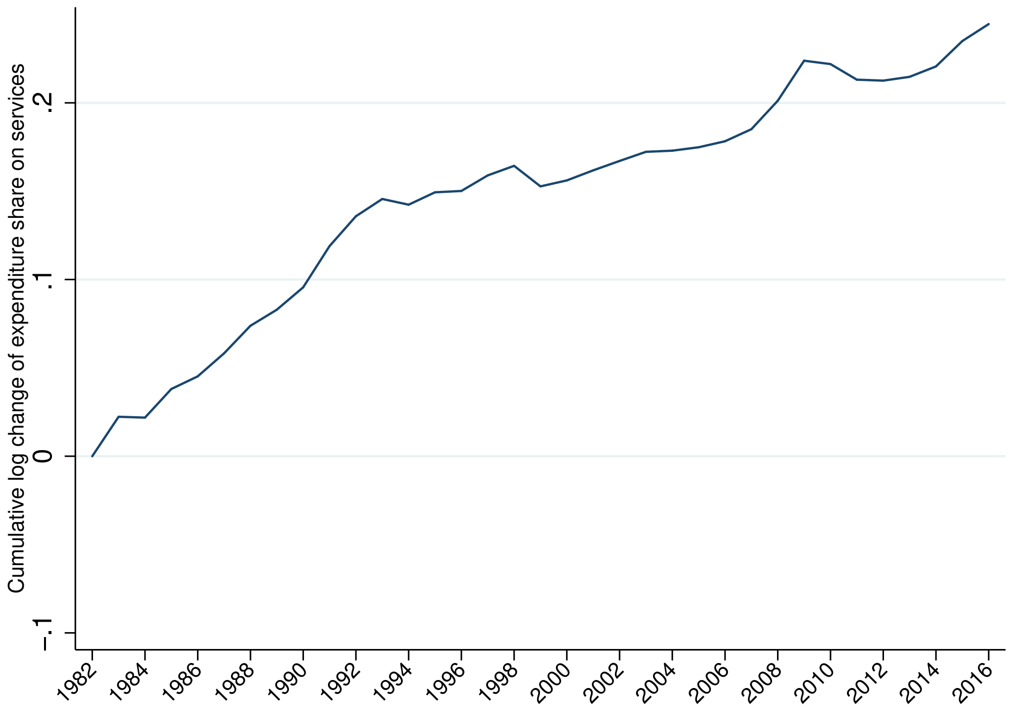
Using the rescaled expenditures, we compute the expenditure shares $\omega_t^{j,h} \equiv e_t^{j,h} / \sum_j e_t^{j,h}$, and the total expenditures by household: $e_t^h \equiv \sum_j e_t^{j,h}$. From this, we compute the new e_t^h / e_t. These steps give us all the elements of a new dataset, on which we repeat the household-level estimation in Section 2.2 and the quantitative analysis of Section 3. This approach relies on the assumption that the micro variation across households in the CES is an accurate reflection of the differences in spending patterns by age group. In the main text, we argued based on evidence from another survey that this is likely to be the case with healthcare, where the ratio to out-of-pocket to total expenditure is stable across age groups. Unfortunately, similar data on other categories of public expenditures by age group are not readily available. A particularly concerning category is education, which is a service consumed disproportionally by the young where public expenditures are large. We construct a lower bound for the effect of aging on the service share of consumption by adopting the extreme assumption that all of the public education expenditure goes to the younger (below 65) households.[12] The age profile of service consumption is quite similar to the baseline reported below.

Replication of main results using rescaled data Figure A17 plots the cumulative log change in the aggregate expenditure share on services in the BEA PCE data. These data show a somewhat larger change than the CES, with the expenditure share of services rising by 0.24 log points. Figure A18 shows the service expenditure shares for households of different ages, and the three time periods. It also displays the age dummies controlling for income, as in equation (2). The magnitudes of the differences across households are similar to the baseline analysis. Figure A19 breaks down by income quartile. The results are quite similar to the baseline.

[11] The CES collects expenditures from households surveys, while the BEA final sales made by businesses in a way that is consistent with the National Income and Product Accounts.

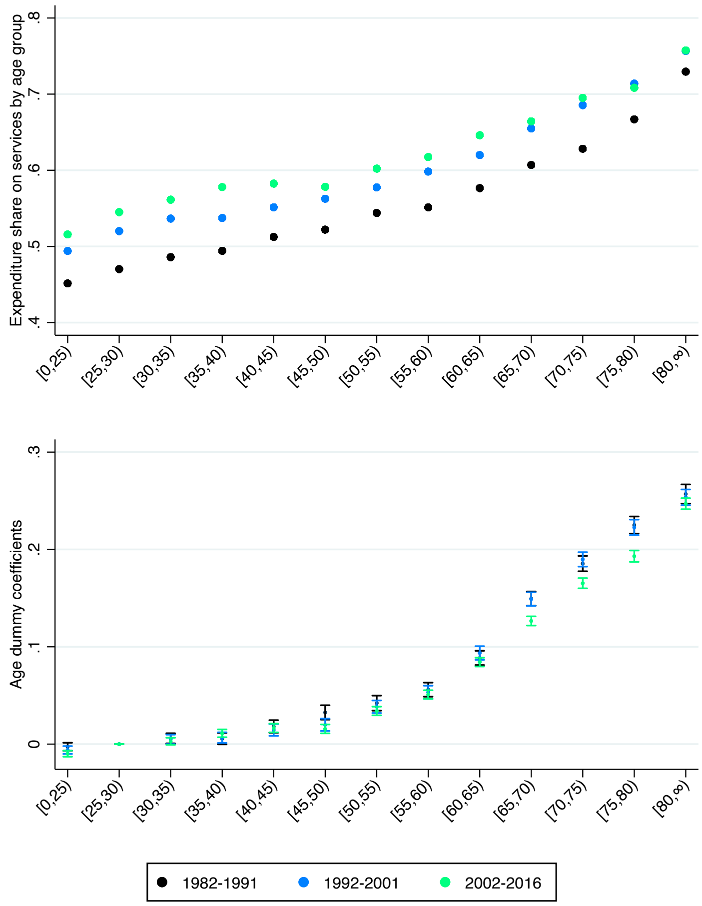
[12] That is, we rescale the CES data to match the BEA aggregates, assuming that the over-65s receive zero public education expenditure. This gives us an lower bound on the impact of aging on the service share, since education is a service and we are in effect increasing the service expenditure share of the young by more than the old.

Figure A17: Service consumption share, BEA



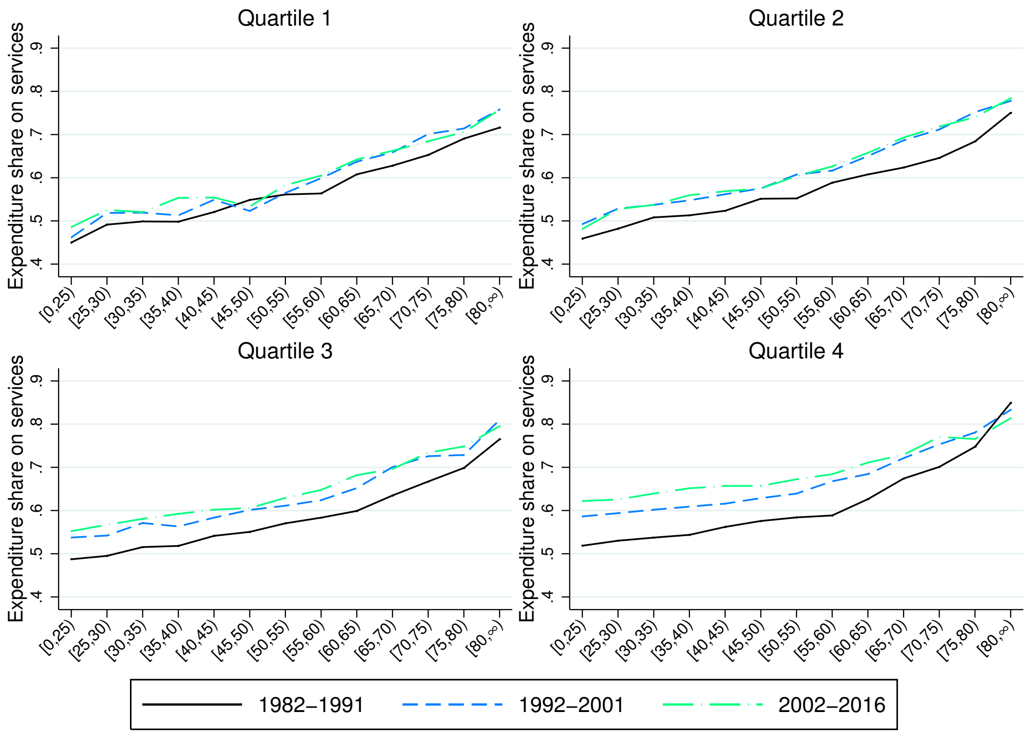
Notes: This figure displays the cumulative log change in the aggregate expenditure share on services in the BEA. Housing is excluded from expenditures.

Figure A18: Service consumption by average age of household members, rescaled to BEA



Notes:The top panel displays the average household-level expenditure shares on services in the CES, rescaled to BEA, by age group (x-axis), for 3 time periods. The bottom panel displays the age dummies resulting from estimating equation (2). Each dot represents the point estimate of the age dummies for a particular decade in the CES data. The omitted dummy is that of age group 25-30. The bands report the 95% confidence intervals based on standard errors clustered at the household level.

Figure A19: Service consumption by average age of household members and income, rescaled to BEA

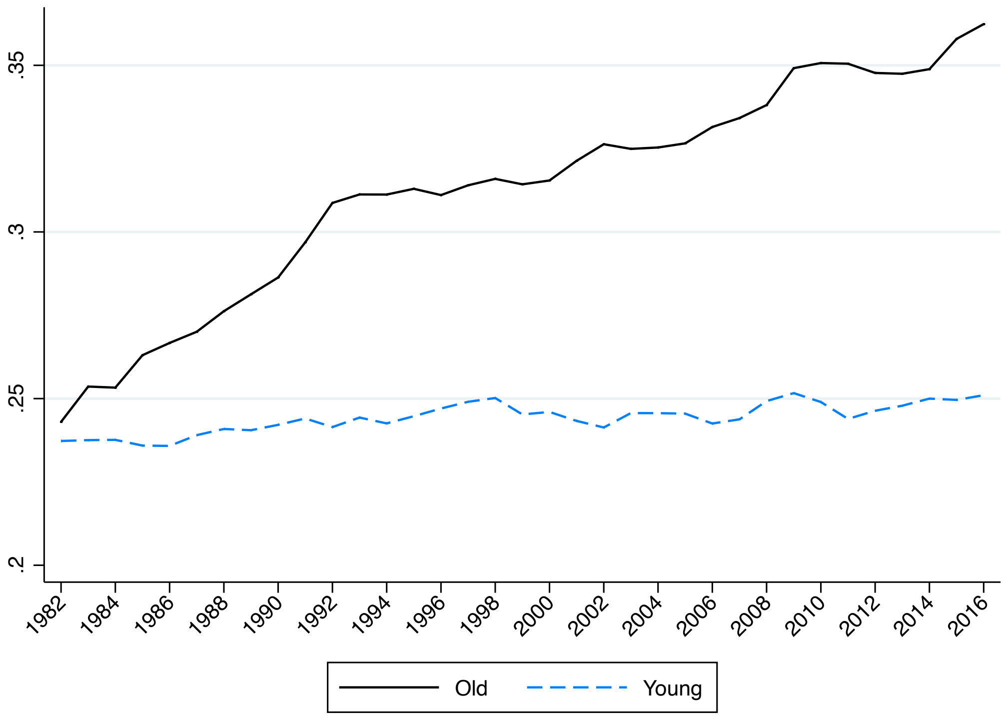


Notes: This figure displays the average household-level expenditure shares on services in the rescaled CES by age group (x-axis), for 3 time periods, and each income quartile.

Table A9 reports the differences in consumption expenditures by category for older households, expressed as a difference relative to the households aged 25-30. While the ranking of categories according to young-old expenditure share differences is similar, the BEA-rescaled data show larger absolute differences in Healthcare.

Moving on to the replication of the results in Section 3, Table A10 reports the changes in the services expenditure shares and income shares, and the within-between decomposition. In the BEA-rescaled data, the absolute size of the between effect due to population aging is slightly larger than in the baseline. However, because the change in the aggregate service expenditure share is also larger in the BEA, the between effect represents 14.3% of the total rise in the service expenditure share.

Figure A20: Evolution of expenditure share on selected service categories using CES and re-scaling to BEA



Notes: 'Old' displays the aggregate expenditure share in the BEA on categories that are disproportionally consumed by the old: Health, Utilities, and Domestic Services and Childcare. 'Young' displays the expenditure share on the remaining service categories.

Table A9: Differences in expenditures by consumption category: 25-30 vs 60-65, 65-70, 70-75, 75-80 and 80+, rescaled to BEA

	Age groups				
	60-65	65-70	70-75	75-80	80+
Health	9.47	13.40	17.07	20.98	24.95
Cash contributions	2.28	2.98	3.70	4.23	6.11
Domestic services and childcare	0.10	0.28	0.47	0.93	3.07
Utilities	-0.06	-0.09	0.11	0.36	0.56
Personal care services	-0.01	0.03	0.08	0.10	0.12
Personal care goods	-0.01	-0.01	-0.01	-0.01	-0.01
Public transport	0.10	0.07	-0.07	-0.15	-0.67
Tobacco	-0.12	-0.34	-0.56	-0.77	-0.96
Furnitures and Fixtures	-0.29	-0.38	-0.60	-0.73	-0.98
Shoes and other apparel	-0.52	-0.63	-0.75	-0.94	-1.00
Children's clothing	-0.83	-0.85	-0.95	-1.00	-1.08
Appliances	-0.13	-0.37	-0.57	-0.73	-1.12
Alcoholic beverages	-0.55	-0.71	-0.91	-1.12	-1.33
Personal Insurance	3.29	1.90	0.82	-0.96	-1.71
Men's and women's clothing	-0.66	-0.94	-1.13	-1.50	-2.02
Entertainment fees, adm., reading	-0.71	-0.91	-1.19	-1.66	-2.28
Entertainment equipment	-0.60	-1.05	-1.72	-2.01	-2.41
Car maintenance, repairs	-0.91	-1.21	-1.43	-1.53	-2.47
Education	-2.29	-2.46	-2.49	-2.43	-2.57
Gas	-1.05	-1.36	-1.70	-2.05	-2.80
Food at home	-2.93	-2.91	-2.61	-2.32	-2.88
Food away from home	-1.71	-2.11	-2.71	-3.32	-4.16
Vehicle purchasing, leasing	-1.87	-2.32	-2.82	-3.36	-4.36
Services	9.54	11.88	14.35	16.56	20.95

Notes: This Table reports the differences in expenditure shares across the major consumption categories between households aged 60-65 (first panel) or 80+ (second panel) and households aged 25-30. Source: authors' calculations based on the CES, rescaled to BEA.

Table A10: Population aging and the services share, rescaled to BEA

Panel A: Expenditure shares across the age distribution

	Pop 1982	s^a_{1982}	$\omega^{s,a}_{1982}$	Pop 2016	s^a_{2016}	$\omega^{s,a}_{2016}$
0-25	31.8	30.2	45.6	20.4	18.4	58.5
25-30	13.5	15.5	48.1	11.4	11.5	60.7
30-35	9.4	11.1	49.6	9.4	10.5	63.2
35-40	6.2	7.5	51.2	7.1	7.7	62.7
40-45	4.6	5.4	52.9	5.9	6.6	66.1
45-50	3.6	4.0	55.4	5.2	5.6	65.1
50-55	3.8	4.0	53.4	6.1	6.0	64.7
55-60	5.1	5.2	55.3	6.7	7.2	68.1
60-65	5.7	5.6	58.5	7.5	8.1	70.3
65-70	5.9	5.0	61.1	6.8	6.9	70.6
70-75	4.3	3.1	64.2	5.1	5.0	72.1
75-80	3.3	2.0	64.3	3.4	3.0	72.5
80+	2.9	1.4	70.9	5.0	3.6	77.4

Panel B: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.1187	85.7	0.1198	86.5
Between	0.0197	14.3	0.0187	13.5
Total	0.1385	100	0.1385	100

Notes: In Panel A, 'Pop' reports the share of the population in each age group, and s^a_t and ω^a_t are defined as in Equation (4). Panel B reports the results of the decomposition in equation (4). 'Average' uses the average age across all household member as the age of the household. 'Reference' uses the age of the head in the household.

Tables A11-A12 re-estimate the model parameters on the BEA-rescaled data, while Figure A21 reports the decomposition of the US structural change. The income effect plays a higher role compared to the baseline results, but none of the substantive conclusions change when using these data. Population aging still contributes about 0.05 log points to the change in the service share since 1982, same as in the baseline. This absolute contribution is smaller as a proportion of the total, since the aggregate service share rises by more in the BEA than the CES.

Table A11: Estimates of equation (8), rescaled to BEA

	(1)	(2)	(3)	(4)
Dep. var.: $\ln \omega_t^{g,n}$				
$\ln e_t^n$	-0.143***	-0.143***	-0.234***	-0.236***
	(0.000732)	(0.000730)	(0.00199)	(0.00200)
Type	OLS	OLS	IV	IV
Time FE	Yes	No	Yes	No
Region-Time FE	No	Yes	No	Yes
Observations	1,325,614	1,319,821	1,226,650	1,221,020
R^2	0.198	0.202	0.168	0.171

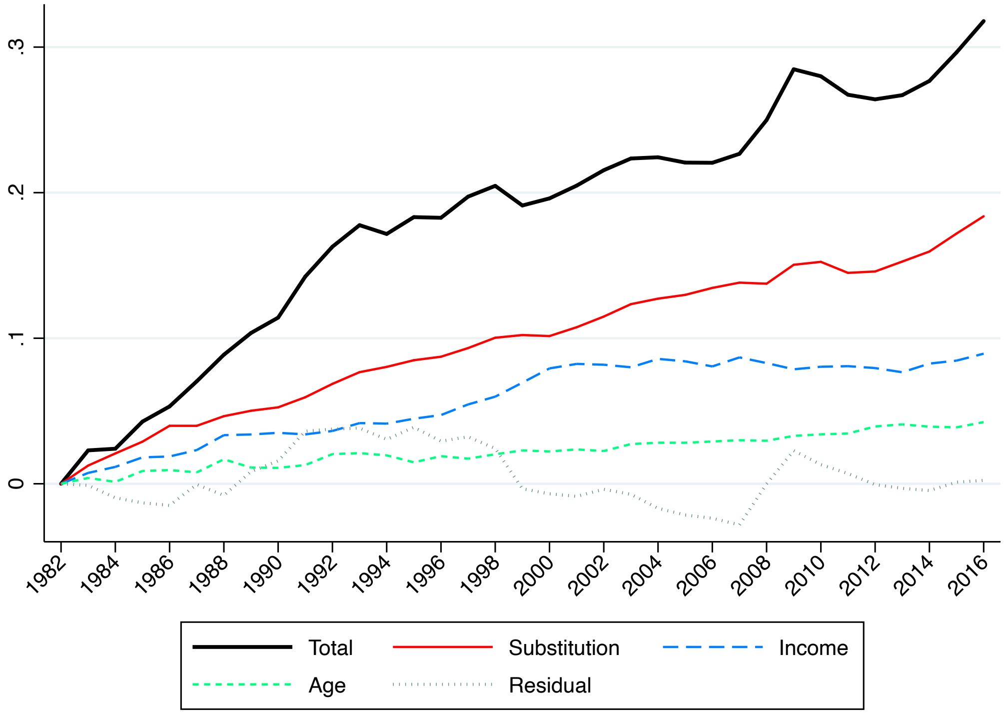
Notes: This table reports the results of estimating equation (8). The outcome variable is household expenditure share on goods. Standard errors clustered at the household level in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Table A12: Estimates of equation (9), rescaled to BEA

	(1)	(2)
Dep. var.: $\ln \Omega_t^g$		
$b_1 = \gamma$	0.346***	0.360***
	(0.00799)	(0.00790)
Age variable	Average	Reference
Observations	35	35
R^2	0.982	0.984

Notes: This table reports the results of estimating equation (9). The outcome variable is aggregate expenditure share on goods. Standard errors in parentheses. *: significant at 10%; **: significant at 5%; ***: significant at 1%.

Figure A21: Accounting for structural change in the US, rescaled to BEA.



Notes: This figure displays the decomposition (10) for the US from 1982 to 2016, using data rescaled to BEA.

B.4 Changes in relative number of households vs. relative income

The results in Section 3 arise from changes in the share of each age group in total expenditures across time. The share of age group a in aggregate expenditures can be written as:

$$s_t^a \equiv \frac{\sum_j e_t^{j,a}}{\sum_a \sum_j e_t^{j,a}} \;=\; n_t^a \times \tilde{e}_t^a,$$

where $n_t^a \equiv N_t^a / \sum_a N_t^a$ is the share of households that are in age group a, and $\tilde{e}_t^a \equiv \frac{\sum_j e_t^{j,a} / N_t^a}{\sum_a \sum_j e_t^{j,a} / \sum_a N_t^a}$ are the expenditures per household of age group a relative to expenditures per household in the economy. This appendix explores how large is the contribution of aging to structural change if we instead focus solely on the shares of households component of changing expenditure shares, n_t^a.

B.4.1 Within-between decomposition

To focus on the role of changes in the share of households that are in age group a, we perform a within-between decomposition on the *average* service expenditure share across household age groups, rather than on the *aggregate* service expenditure share in the economy. The average expenditure share in services across age groups is defined as

$$\omega_t^s \;\equiv\; \sum_a n_t^a \omega_t^{s,a},$$

and can be decomposed into

$$\Delta\omega^s = \underbrace{\sum_a \Delta\omega^{s,a} \cdot \overline{n}^a}_{\text{Within}} + \underbrace{\sum_a \overline{\omega}^{s,a} \cdot \Delta n^a}_{\text{Between}}, \tag{B.1}$$

where ω^s is the cross-age group average share of services expenditure. The average ω_t^s and aggregate Ω_t^s shares are very similar, and thus experienced very similar changes over this period (ω^s went from 0.447 in 1982 to 0.524 in 2016, whereas Ω^s went from 0.435 to 0.520). So the decomposition of the average (B.1) should still be informative, while at the same time focusing purely on the population changes Δn^a rather than expenditure share changes Δs^a. Table A13 below presents the results of the decomposition (B.1). The results are quite similar to the baseline. The contribution of the Between effect is still about 20% of the total.

Table A13: Within-between decomposition

	Average		Reference	
	Value	%	Value	%
Within	0.0636	81.8	0.0660	83.7
Between	0.0141	18.2	0.0128	16.3
Total	0.0777	100	0.0789	100

Notes: The table reports the results from the decomposition in equation (B.1). 'Average' uses the average age across all household member as the age of the household. 'Reference' uses the age of the reference person in the household.

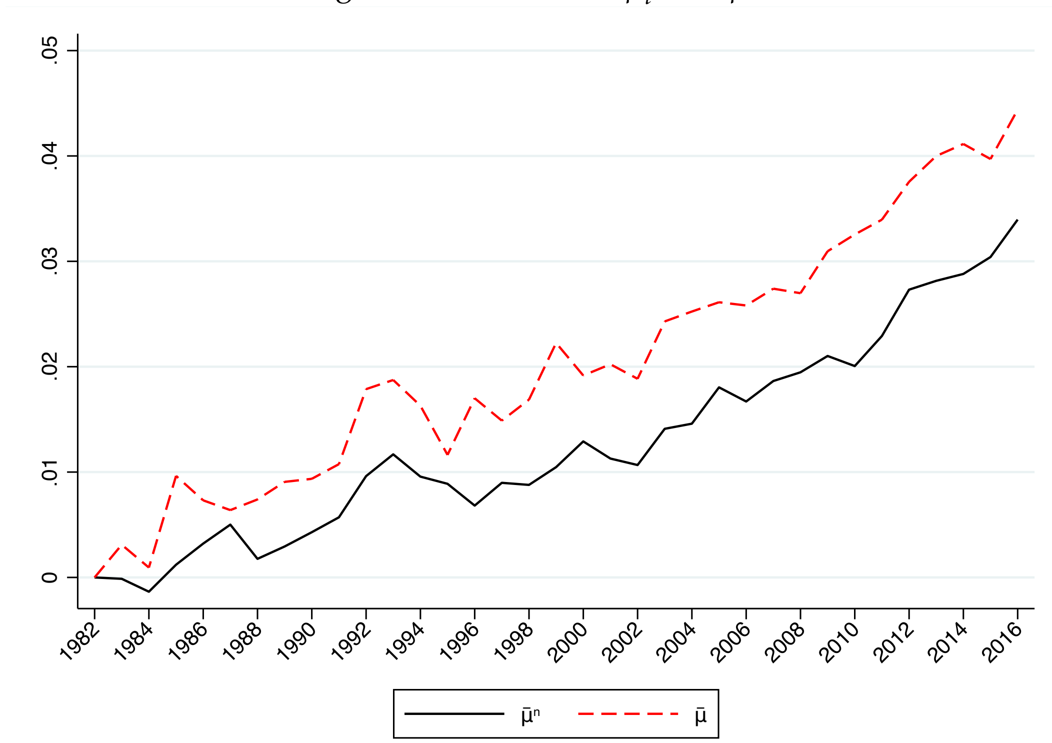
B.4.2 Structural model

To focus purely on changes in household numbers by age group, we implement an alternative version of equation (7):

$$\Omega_t^g = \left[\frac{P_t^s}{e_t}\right]^{\epsilon} \left[\frac{P_t^g}{P_t^s}\right]^{\gamma} \bar{\mu}_t^n \phi_t^n \nu_t,$$

with $\bar{\mu}_t^n \equiv \sum_a n_t^a \mu^a$ and $\phi_t^n \equiv \frac{1}{N_t} \sum_h^{N_t} \frac{\mu^a}{\bar{\mu}_t^n} \left[\frac{e_t^h}{e_t}\right]^{1-\epsilon}$. Note that this alternative simply redefines the aggregate aging term $\bar{\mu}_t$ to sum over number of households shares n_t^a instead of expenditure shares s_t^a. While this affects the inequality term ϕ_t, it leaves the rest of the decomposition unchanged, and thus the Income and Substitution terms in (10) are the same as in the Baseline. Figure A22 plots the original Aging component of (10), $\hat{\mu}_t$, alongside the alternative $\hat{\mu}_t^n$. The two are quantitatively similar, though the latter has a somewhat smaller contribution.

Figure A22: Measures $\bar{\mu}_t^n$ and $\bar{\mu}_t$



Notes: This figure displays the changes across time of two different aging measures from the structural model. $\bar{\mu}_t \equiv \sum_a s_t^a \mu^a$ and $\bar{\mu}_t^n \equiv \sum_a n_t^a \mu^a$.

B.5 Derivation of equation (10)

We are interested in computing the elasticity of the expenditure share on goods with respect to the relative price of goods $\frac{P_t^g}{P_t^s}$. To compute this elasticity, solve for e_t^h to obtain the expenditure function associated with the utility level $\mathcal{V}^h$:

$$\begin{aligned} \frac{1}{\epsilon}\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon} &= \mathcal{V}^h + \frac{\nu_t^h}{\gamma}\left[\frac{P_t^g}{P_t^s}\right]^{\gamma} + \frac{1}{\epsilon} - \frac{\nu_t^h}{\gamma} \\ e_t^h &= P_t^s\left\{\epsilon\left[\mathcal{V}^h + \frac{\nu_t^h}{\gamma}\left(\frac{P_t^g}{P_t^s}\right)^{\gamma} + \frac{1}{\epsilon} - \frac{\nu_t^h}{\gamma}\right]\right\}^{\frac{1}{\epsilon}}. \end{aligned}$$

By Roy's identity, the demand for goods is:

$$c_t^{g,h} = \frac{\nu_t^h\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\frac{1}{P_t^g}}{\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon-1}\frac{1}{P_t^s}} = \frac{\nu_t^h\left[\frac{P_t^g}{P_t^s}\right]^{\gamma}\frac{e_t^h}{P_t^g}}{\left[\frac{e_t^h}{P_t^s}\right]^{\epsilon}},$$

and therefore the goods spending share is:

$$\omega_t^{g,h} = \frac{\nu_t^h \left(\frac{P_t^g}{P_t^s}\right)^{\gamma}}{\epsilon \left[\mathcal{V}^h + \frac{\nu_t^h}{\gamma}\left(\frac{P_t^g}{P_t^s}\right)^{\gamma} + \frac{1}{\epsilon} - \frac{\nu_t^h}{\gamma}\right]}.$$

The elasticity of this share with respect to $\frac{P_t^g}{P_t^s}$ is:

$$\gamma - \epsilon\omega_t^{g,h}.$$

Then at the household level, the substitution effect is defined as

$$\left(\gamma - \epsilon\omega_t^{g,h}\right)\left[\hat{P}_t^g - \hat{P}_t^s\right].$$

As Muellbauer (1975, 1976) shows, this economy admits a representative agent, defined as the household that exhibits the aggregate expenditure shares. In our framework, this is the household with income $e_t^{rep} \equiv e_t \left(\bar{\mu}_t \phi_t \nu_t\right)^{-\frac{1}{\epsilon}}$. This allows us to define the aggregate substitution effect as just the substitution effect of the representative consumer, or:

$$\left(\gamma - \epsilon\Omega_t^g\right)\left[\hat{P}_t^g - \hat{P}_t^s\right]. \tag{B.2}$$

The log change in the aggregate expenditure share (7) is:

$$\hat{\Omega}_t^s \approx -\frac{\Omega_{82}^g}{\Omega_{82}^s}\left\{\epsilon\left[\hat{P}_t^s - \hat{e}_t\right] + \gamma\left[\hat{P}_t^g - \hat{P}_t^s\right] + \hat{\bar{\mu}}_t + \hat{\phi}_t + \hat{\nu}_t\right\}. \tag{B.3}$$

The first two terms, $\epsilon\left[\hat{P}_t^s - \hat{e}_t\right] + \gamma\left[\hat{P}_t^g - \hat{P}_t^s\right]$ can be thought of as capturing the sum total of the income and substitution effects. They can be combined with (B.2) to isolate the two effects separately, leading to (10).